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THE OPTIMAL POSITION OF A REST PERIOD IN LEARNING[1]

BY VIVIENNE ROBISON McCLATCHY

Florida State College for Women

INTRODUCTION

The general purpose of this study is an investigation of the influence upon maze learning of the interpolation of a single rest period of definite length at various places in the learning process.

This problem is part of the general topic of the distribution of effort which has been attacked from various angles. The earlier investigations along this line were concerned simply with the relative value of massed *vs.* distributed effort in learning. The studies of Ebbinghaus (3) and Jost (5) are investigations of the problem from this aspect. It soon became evident that the problem of distribution of effort was not so elementary in nature, for the results indicated clearly that several factors were operating to produce the differences which had ordinarily been assumed to belong either to accumulation or distribution. Two aspects of the problem were then made the subject of rather extensive investigation: (*a*) the relation of the length of the interval to efficiency of effort, investigated by Perkins (8), Pyle (9), and others; (*b*) the relation of the frequency of the interpolated interval to efficiency, investigated by Ebbinghaus (4), Perkins (8), Jost

[1] This investigation was done under the direction of Prof. H. A. Carr, in the laboratory at the University of Chicago, 1923–24.

(5), Lashley (6), and Pyle (9). These studies, however, failed to take into account a third aspect, viz., the possibility that the efficiency of a rest period will vary with the position at which it is inserted. By introducing a rest period of a given length at regular intervals throughout the learning process, the earlier studies practically assumed that the influence of these rest periods is the same, no matter where introduced. A final answer to the problem of the most efficient distribution thus raises the more fundamental problem as to *whether or not the length of the rest period should be varied according to the position of interpolation.* Those studies which present evidence that bears either directly or indirectly upon this problem, do not arrive at a common conclusion. Jost (5) found that the optimal distribution of study is manifested if the early learning be massed and the later learning be distributed. In Lashley's (6) experiments in archery, he found that distribution of practice is most effective in the later stages of learning. Carr (1) and Ulrich (11) found that learning a maze is accomplished more quickly if the practice be distributed in the early stages of learning. A conclusion similar to the one just mentioned was reached by Steffens (10) in her study in which the material used was nonsense syllables. Cummins (2) found that short infrequent intervals may be more economical in the early stages of learning while long and infrequent intervals may be superior in the later stages for certain types of material. The object of this present inquiry is to study the question stated above and to attempt to determine the optimal locus of a given rest period in the process of learning.

The type of activity used for investigation was the learning of a simple stylus maze which is described later. The general method of procedure consisted in interpolating a specific rest period at different stages in the learning process by allowing the subjects to make a certain number of trials at the first sitting and then to complete the learning at the second sitting, which came at the end of the rest period. The main part of the experiment is concerned with a rest period of 48 hours inserted after the first, third, fifth, seventh, ninth and eleventh

trials respectively, though some supplementary investigation was done in connection with a twenty-four hour rest period inserted after three, five and nine trials respectively. The results from these records were compared with those of a normal group, each member of which completed the learning at a single sitting.

The specific questions upon which this study will attempt to cast light are:

1. Is the interpolation of a given rest period in learning effective?

2. Is this effect always beneficial, or is it sometimes detrimental?

3. In either case, is the effect noticeable immediately or is it of a delayed nature?

4. At what stages in the learning does there occur the most pronounced effect of either sort?

5. Is the effect, whether beneficial or detrimental, confined to one criterion or does the nature of the effect change with different criteria?

6. Is the effect widespread as to the number of individuals influenced, or is it restricted to a few?

7. Is the optimal position of a rest period of a given length also the optimal position for a rest period of a different length?

The apparatus employed throughout the experiment was the small stylus maze used by M. C. Hardy in her work on 'The Effect of Distribution of Practice in Learning a Stylus Maze' [1] and similar in pattern to that used by C. J. Warden in his work 'The Distribution of Practice in Animal Learning' (12). The cul-de-sacs and the true pathway, which were milled out of a solid brass casting, were $\frac{1}{4}$ in. wide and $\frac{1}{4}$ in. deep. The partitions between these grooves were likewise $\frac{1}{4}$ in. wide. The outside dimensions of the maze were $7\frac{1}{4}$ in. by $6\frac{3}{4}$ in.

The maze was concealed by means of a heavy black curtain covering the top and three sides of a steel frame. This frame was 20 in. wide, 15 in. deep, and 18 in. high, corresponding in width and depth to the top of the stand, upon which the maze

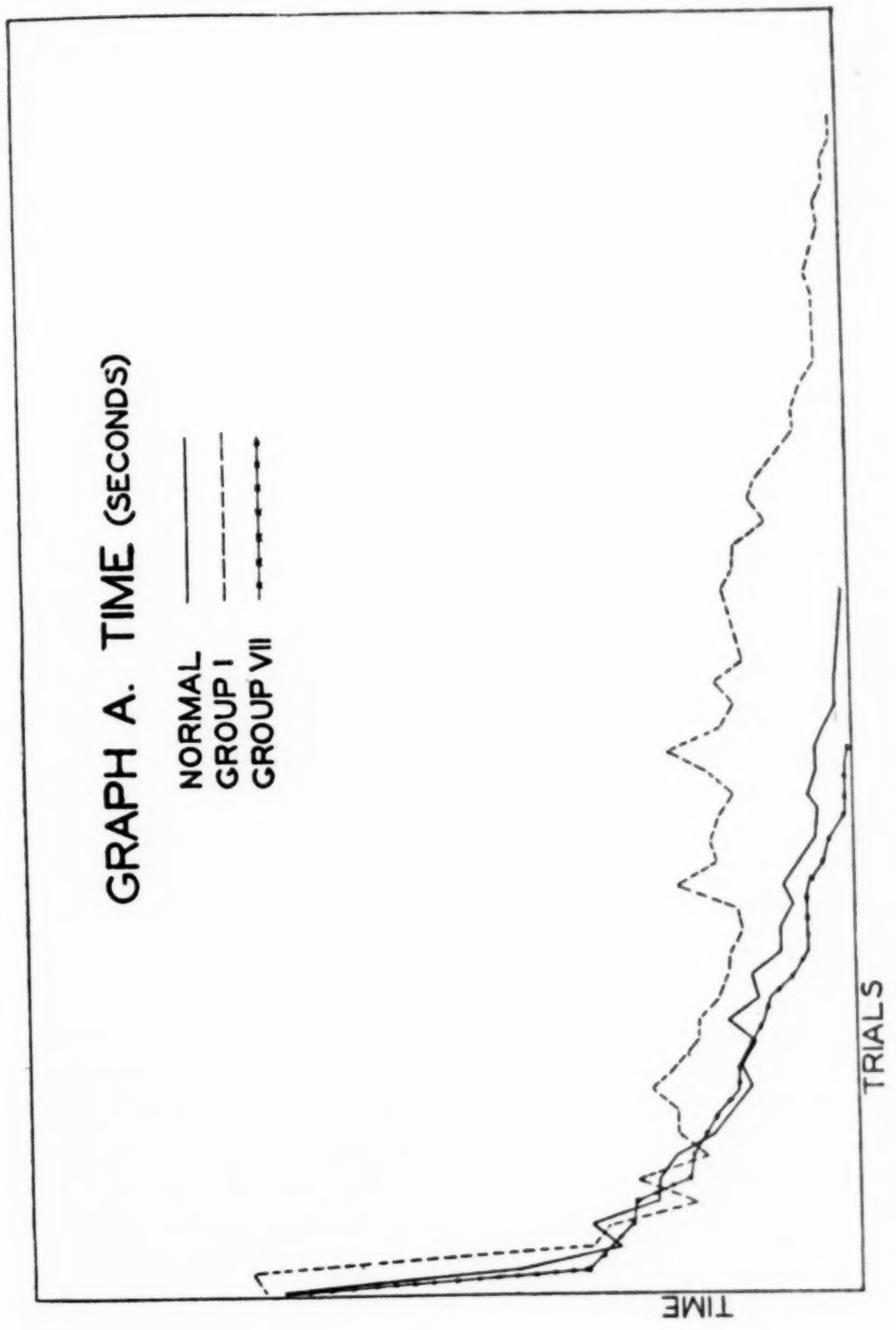
[1] This manuscript is as yet unpublished.

was tightly fastened. From the side of the steel frame which was uncovered, the experimenter could observe the progress of the subject without herself being observed.

The subjects were required to trace the maze with a hard rubber stylus, the lower end of which was 3/16 in. in diameter. It could easily be guided through the groove. A small rubber shield 5/16 in. from the end of the stylus prevented the hand of the subject from coming in contact with the maze. Errors consisted of: (*a*) every entrance into a cul-de-sac, when the subject was tracing *away* from the starting point; (*b*) every retracing, whether it was of a unit of the true pathway or the return entrance into a cul-de-sac. The criterion of learning was four successive perfect trials. Time, measured by a stop watch with seconds as units, was recorded from the moment that the stylus was set in motion at the starting point until the end was reached, where an electric buzzer was sounded.

The subject was seated at the table and the following directions were read to him: "Please put under the curtain the hand which you use most, the right or left as the case may be. Grasp the stylus and hold it as erect as possible, being sure that neither your hand nor arm touches the apparatus. Keeping the stylus in the groove, explore the maze until you come to the end where a buzzer will sound. Use any method you choose. The aim of the experiment is to find the shortest possible route through the maze." When the subject placed his hand under the cover, the experimenter gave him the stylus and then placed his hand at the starting point. Then the experimenter said to the subject, "Now you are in the groove. Explore the maze until you hear the buzzer sound." Errors and time for each trial were recorded on a blank arranged for the purpose. On account of the black curtain, the subject could not see what the experimenter was doing, so that his efforts could not possibly be modified by any activity on the part of the experimenter.

For the main part of the experiment on the 48 hour rest period, six groups of subjects were used. These groups are designated according to the trial after which the rest period is inserted. For example, Group I. consists of those individuals


GRAPH A. TIME (SECONDS)
NORMAL
GROUP I
GROUP VII
TIME
TRIALS

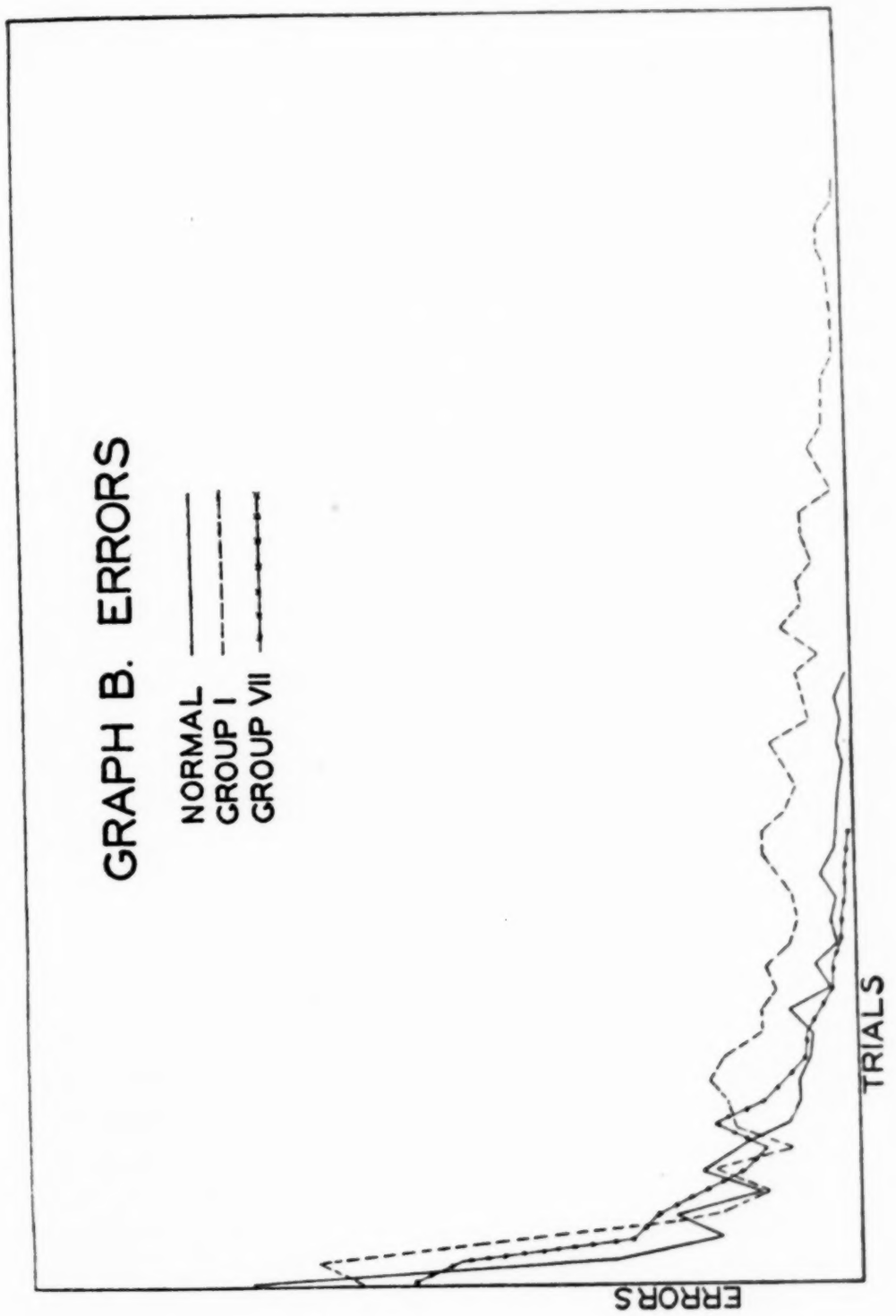
who made one trial the first sitting, and returned forty-eight hours later, staying until they had completed the learning; Group III. made three trials at the first sitting and completed learning after forty-eight hours; Group IX. made nine trials the first sitting and completed learning forty-eight hours later, etc. For the supplementary series the procedure was the same and the groups were designated in the same manner, but the length of the rest period was twenty-four hours instead of forty-eight.

Each of the six groups in the main series, as well as the normal group, contained twenty-four individuals. Two of the groups of the main series each had fifteen additional subjects put in to increase the validity of their results, and the groups in the supplementary series were composed of fifteen subjects each. This made a total of two hundred forty-three subjects in the experiment. These were all undergraduate students from the University of Chicago and the University of Texas. The subjects were naïve as far as the maze was concerned, and the groups were unselected due to the fact that participation in the experiment was made a part of the work in the introductory psychology classes from which the subjects were drawn. Assignment to groups was a matter of chance distribution due to the fact that the subjects were fitted into the schedule on which the experimenter was working. When the subject came, he was simply put into the group upon which the experimenter happened to be working at that time.

Series A. Rest Period of Forty-eight Hours

Let it be recalled that in this series there were originally six groups of twenty-four each. The forty-eight hour rest period was inserted after the first, third, fifth, seventh, ninth and eleventh trials respectively, and the groups, as has been previously stated, are designated according to the trial after which the rest was interpolated. Twenty-four individuals were required to complete the learning in one sitting. These constituted the normal group. The average results from the normal group and from Series A are found in Table I.

It is possible that these final values may be due to group


GRAPH B. ERRORS
NORMAL
GROUP I
GROUP VII
ERRORS
TRIALS

differences which were not wholly eliminated by the size of the groups and the method of selection. It has been suggested that any possible group differences will be revealed by the initial time and error records. These data are given in Table I. From an inspection of this table it is evident that the

TABLE I

Group	Av. No. of Trials	Av. Initial time	Av. time in Sec.	Av. Initial Error	Av. No. of Errors
Normal.....	20	127.4	751	27	96.4
I.....	27	178.4	1,158	26	100.09
III.....	26	130.4	1,133	23	108.4
V.....	24	167.1	1,111	40	207.0
VII.....	17	127.0	722	20	81
IX.....	20	160.1	970	27	148
XI.....	22	196.2	1,029	19	90
Average.....		149.5		26	

initial values do vary considerably from group to group, but that they exhibit no high degree of correlation with the final values except in the case of the initial time values with the average time and trial records. It must be admitted, however, that the lack of any high degree of correlation between the initial and final records does not prove that these latter values are not due to chance, and by the same token it follows that a high correlation would not necessarily indicate that the factor of chance is responsible for the final scores.

Another test of the validity of the results is to be found in the general consistency in the results themselves. If the rest period be interpolated after the first trial, the average number of trials required for learning is 27; if the rest be put in after the third trial, the number of trials required for learning is 26; if the rest be put in after the fifth trial, the number of trials required is 24. There is then a consistent decrease in the number of trials necessary for learning as the interpolation is moved away from the beginning of the learning until the lowest point—seventeen trials—is reached at the seventh trial. From this point on, the number of trials increases consistently through Groups IX. and XI. The time follows the same general tendency as the number of trials. It is not at all

probable that this regular variation of the time and trial records with the changes in the position of rest can be due to chance. The error records are not so consistent as those of the trials and time, though they do show a general tendency which may be stated thus: as the number of trials decreases there is an increase in the number of errors. There is an exception to this in Group VII. where both the trial record and error record are low. Since this occurrence cannot be explained in terms of initial error, as indicated above, an explanation must be sought elsewhere.

The records were then subjected to further statistical treatment, each method of measuring the learning—trials, time, and errors—being treated separately. Tables II., III., and IV. contain these results, after they were so treated and so separated.

Table II

Trial Table

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
I.....	648	27	19	14.5	1.956
III.....	624	26	23	12.5	1.686
V.....	576	24	19.5	9.9	1.349
VII.....	423	17	19	4.6	.621
IX.....	480	20	20	5.05	.694
XI.....	550	22	20.5	8.1	1.079

Table III

Time Table (Seconds)

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
I.....	27,799	1,158	1,132	552.1	77.567
III.....	27,206	1,133	775.5	592.8	82.963
V.....	26,668	1,111	847.5	570.9	79.591
VII.....	17,374	722	586	371.2	51.936
IX.....	23,280	970	680	373.4	52.611
XI.....	24,716	1,029	897	515.8	62.171

It will be seen immediately on looking at the preceding tables that there is considerable consistency within the results themselves. As far as trials are concerned, the medians, with one exception, are all smaller than the averages, and except in the case of Group I., they follow the same tendency as do the

averages. The standard deviation also shows the same tendency. Consideration of the time table shows that again the medians are all smaller than the averages. With the exception of Group V., the same tendency is exhibited for medians of the time as is exhibited for the averages, and the standard

TABLE IV

ERROR TABLE

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
I.....	2,402	100.09	79	58.6	8.296
III.....	2,602	108.4	93	62.2	8.498
V.....	4,971	207	152	182.7	25.091
VII.....	1,946	81	83	38.7	5.261
IX.....	3,552	148	154.5	81.3	11.129
XI.....	2,161	90	90	49.3	6.745

deviation, with the exception of Group I., also follows the tendency of the averages. Observation of the error table shows that both the medians and the standard deviations follow the tendency of the averages and that the error medians are smaller than the error averages with two exceptions. From these facts we may conclude that with few exceptions the medians and standard deviations show the same tendency as do the averages, which fact indicates that the results show a considerable degree of validity, with the possible exception of the median values for trials in Group I.

This validity was then tested by repeating the experiment for two groups. This was an attempt (1) to determine whether the results could be duplicated and (2) to increase the number in these two groups in order to secure greater validity for statistical comparison. Since Group I. was the group in which the greatest number of trials was required for learning and the divergence of the median was greatest, and since Group VII. was the group in which the fewest trials were required for learning, it was thought advisable to increase each of these groups by 15 additional records to see if these extremes would be modified. Tables V. VI. and VII. show the results from the original records and from these supplementary records after they had been given statistical treatment similar to the original groups.

TABLE V

TRIAL TABLE

Group	Total	Average	Median	Stan. Dev.	P. E.
I. (Original)	648	27	19	14.5	1.956
I. (Supplementary)	427	28	28	8.3	1.618
VII. (Original)	423	17	19	4.6	.627
VII. (Supplementary)	264	17	19	4.0	.701

TABLE VI

TIME TABLE (SECONDS)

Group	Total	Average	Median	Stan. Dev.	P. E.
I. (Original)	27,799	1,158	1,132	552.1	77.567
I. (Supplementary)	16,511	1,100	965	515.0	89.034
VII. (Original)	17,374	722	586	371.2	51.936
VII. (Supplementary)	10,768	717	767	258.1	44.517

TABLE VII

ERROR TABLE

Group	Total	Average	Median	Stan. Dev.	P. E.
I. (Original)	2,402	100.09	79	58.6	8.296
I. (Supplementary)	1,643	109.5	105	64.7	11.466
VII. (Original)	1,946	81	83	38.7	5.261
VII. (Supplementary)	1,254	83.6	92	37.1	6.542

Comparing the supplementary results of Group I. with the supplementary results of Group VII., it is seen that the relation between the two new groups is the same as the relation between the original groups. As far as trials are concerned the comparative standing of the two groups was duplicated for the average and the standard deviation; as far as time is concerned, the average, the median, and the standard deviation were all duplicated; and in respect to errors, the average and the standard deviation were duplicated.

These facts indicate that the differences between Group I. and Group VII. are valid differences and will reappear upon repetition of the experiment under similar conditions.

A combination of the original data with this new supplementary material is shown in Tables VIII., IX., and X.

TABLE VIII

TRIAL TABLE

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
Normal.....	499	20	20	6.6	1.116
I.....	1,075	27	27	12.8	1.389
III.....	624	26	23	12.6	1.686
V.....	576	24	19.5	9.9	1.349
VII.....	687	17	19	4.4	.478
IX.....	480	20	20	5.05	.694
XI.....	550	22	20.5	8.1	1.079

TABLE IX

TIME TABLE (SECONDS)

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
Normal.....	18,023	751	744	306.6	43.1
I.....	44,310	1,136	980	538.5	58.546
III.....	27,206	1,133	775.5	592.8	82.963
V.....	26,668	1,111	847.5	570.9	79.591
VII.....	28,142	721	622	332.3	36.085
IX.....	23,280	970	680	373.4	52.611
XI.....	24,716	1,029	897	515.8	62.171

TABLE X

ERROR TABLE

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
Normal.....	2,334	96.4	83.5	67.7	9.308
I.....	4,045	103.7	81	65.7	7.082
III.....	2,620	108.4	93	62.2	8.498
V.....	4,971	207	152	182.7	25.091
VII.....	3,200	82	90	38.1	4.114
IX.....	3,552	148	154.5	81.3	11.129
XI.....	2,161	90	90	49.3	6.745

In the combined results the following conditions exist: the medians, the averages, and the Standard Deviations all show the same tendency for trials; the time median in Group V. that was inconsistent was not retested; the Standard Deviation of time for Group I. was not changed; the error values which were consistent before, now show a Standard Deviation in Group I. that varies from the general tendency. From the preceding discussion it may be concluded that

repetition of the experiment gave the same relative results and that combination of the results gave the same average results with an adequate degree of consistency as to the medians.

A final effort was then made to establish the validity of the results. This was done by computing the probable error of the difference between the various groups. The results for trials are given in Table XI.

TABLE XI

Between	Difference	P. E. of Diff.	Between	Diff.	P. E. of Diff.
Normal–I....	7	1.77	III.–V.	2	2.14
Normal–III..	6	2.01	III.–VII.	9	1.74
Normal–V....	4	1.10	III.–IX.	6	1.81
Normal–VII..	3	1.20	III.–XI.	4	1.99
Normal–IX...	0		V.–VII.	7	1.42
Normal–XI...	2	1.17	V.–IX.	4	1.50
I–III.....	1	2.17	V.–XI.	2	1.71
I–V.....	3	1.9	VII.–IX.	2	1.71
I–VII.....	10	1.46	VII.–XI.	3	.83
I–IX.....	7	1.54	IX.–XI.	5	1.166
I–XI.....	5	1.73			

Of the twenty-one comparisons, six have a difference which is four times the probable error of the difference, and four more have a difference which is at least three times the probable error of the difference.

The time and error records were treated in a similar manner with the following results: (1) the time records showed five cases in which the difference was four times the probable error, and eight cases in which the difference was more than three times the probable error of the difference; (2) the error records showed four cases in which the difference was four times the probable error of the difference and eleven cases in which the difference was more than three times the probable error of the difference.

These tests of validity indicate clearly enough that the results are due in large part to variation in the position of the rest periods. Inspection of Tables VIII., IX. and X. shows clearly that where the rest is interpolated at varying stages in the learning process there are consistent differences in the time and trials necessary for learning. The effect of rest is

GRAPH C. TIME (SECONDS)
NORMAL
GROUP III
GROUP V
GROUP XI
TIME
TRIALS

detrimental if inserted after the first, third and fifth trials respectively, but becomes less detrimental as the insertion is moved away from the beginning of the learning; after the seventh trial the rest is beneficial; after the ninth trial there is almost no effect as far as trials are concerned, but both the time and errors show an increase when compared to the normal; after the eleventh trial the detrimental effect again appears in the time and trials. From the Tables VIII., IX. and X., as well as from the statements just preceding, it is obvious that the most pronounced detrimental effect comes when the rest is inserted after the first trial, while the only pronounced beneficial effect comes if the rest is inserted after the seventh trial.

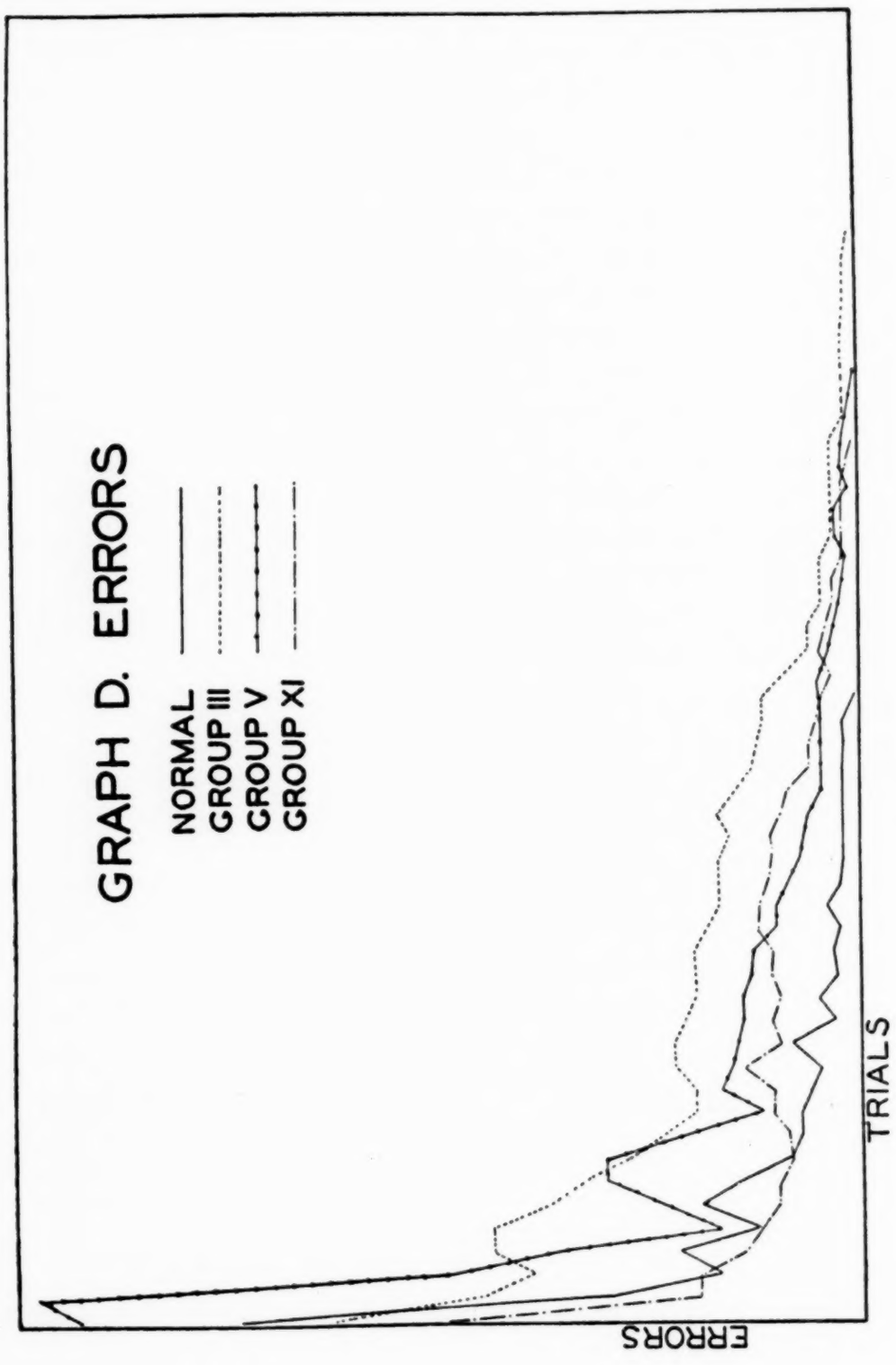
The next problem which presented itself for consideration was in regard to the number of individuals who were affected, *i.e.*, was the effect wide-spread or was it restricted to rather a limited number of individuals? As a possible means of answering this question, it was decided to make a distribution of the trials, time and errors according to the number of individuals who fell in the various intervals. These results are found in Tables XII., XIII. and XIV. These intervals are of five trials each, ranging from below 10 to 55, inclusive.

Table XII

Trial Scatter Table

Group	Below 10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55
Normal...	1	3	7	4	6	3				
I.....		8	8	2	3	7	4	2	2	3
III.....		5	4	4	2	3	3		2	1
V.....		5	7	3		3	3	3		
VII.....		12	12	12	3					
IX.....		4	7	7	4	2				
XI.....			11	4	4	2	2	1		

It will be noticed in the Trial Scatter Table that a considerable amount of variability is in evidence. Comparison of Group I. with the Normal Group shows that there are eleven individuals—28 per cent. of the group—who are distributed above the highest interval in which any individual of the


GRAPH D. ERRORS
NORMAL
GROUP III
GROUP V
GROUP XI
ERRORS
TRIALS

Normal Group fell. This indicates that 72 per cent. of the individuals in Group I. show a tendency which is quite similar to that shown in the Normal Group, or saying it another way, only a relatively small number of this group seem to be detrimentally affected by the insertion of rest. Groups III. and V. show a similar though less pronounced condition. In each of these latter groups 25 per cent. of the individuals are noticeably affected, but in Group V. the effect is not so great because of the fact that the individuals fall in the seventh and eighth intervals while in Groups I. and III. they extend into intervals nine and ten. That is to say: (1) the insertion of a rest period of forty-eight hours after the first, third, and fifth trials respectively produces a detrimental effect which is most evident upon a relatively few individuals; and (2) both the number of individuals influenced and the degree of the effect itself seems to decrease as the insertion of rest is moved away from the beginning of the learning. In Group VII. the whole group seems to be affected, since their records are massed in the lower intervals. This means that the effect here is a beneficial one and that its influence is apparently widespread. In Group IX. as compared with the normal, there is almost no noticeable effect. In Group XI. the whole group is moved up out of the lower intervals and extended slightly beyond the highest interval of the normal group. That is to say, insertion of a rest period after the eleventh trial apparently produces a slightly detrimental effect upon the whole group.

As may be seen from Table XIII., the same general effect exists as far as the distribution of time is concerned.

Table XIII

Time Scatter Table

Group	Below 500	500–1,000	1,001–1,500	1,501–2,000	2,001–2,500
Normal.....	5	17	1		
I.....	6	14	12	4	3
III.....	8	6	6	3	1
V.....	3	11	4	4	2
VII.....	13	20	4	2	
IX.....	3	13	8		
XI.....	3	12	5	2	2

A similar distribution of the error record gives no indication of any regular variability in the errors due to insertion of rest. Table XIV. shows that the relationship between the stage in learning at which the rest is inserted and the distribution of errors is very slight. Group V., *e.g.*, shows a distribution totally unlike the distribution of any other group. The explanation of the distribution of errors must be sought elsewhere.

TABLE XIV

ERROR SCATTER TABLE

Group	0–80	81–140	141–200	201–260	261–320	321–380	381–440	441–500	501–560	561–620	Above 620
Normal	6	11	3	3	1						
I	11	13	5	9	1						
III	5	9	6	2	2						
V	5	4	4	5			1	1	2	1	1
VII	10	17	12								
IX	2	8	5	4	2	3					
XI	7	9	7	1							

Recognition of the existence of an effect, sometimes detrimental and sometimes beneficial, brought up the question of how this effect manifests itself. Is the effect of the rest immediately reflected in the errors and time, or is it a delayed effect? Is it limited to a few trials or does it persist throughout the subsequent trials? Plotting the curves for errors and time was the method used to determine the answers to these questions. Where the whole group seemed to have been affected as in Group VII. and Group XI., all of the records were plotted in comparison with the normal. Where rather a restricted number seem to have been affected as in Groups I., III., and V., only those records which were higher than the highest interval in the normal distribution of trials were used for the curves. This meant, for example, that 39 records in Group VII. and 24 in Group XI. were compared to the Normal, while in Groups I., III., and V. there were eleven, six, and six records respectively included in the curves. Graph *A* for time, and Graph *B* for errors show a sample representation of such plotting. These include the normal curve, the records from all of Group VII. and those individuals in Group I. who

were obviously affected by the insertion of rest, as indicated in the Trial Scatter Table.

In Group I. where the rest is interpolated after the first trial, there is an immediate rise in both the time and error curve. The curves then follow, in general, the contour of the curve of the normal group until the seventh trial is reached, where a rise is evidenced. From this time on the curve remains distinctly higher than the normal for the rest of the time and extends twenty-one trials beyond the culmination of the normal. The indication is that after the insertion of rest there is an immediate detrimental effect which seems to be largely overcome by the next trial. For about five trials then there is no noticeable effect. Then, as the rise of the curve indicates, the detrimental effect is evident and persists throughout the subsequent trials.

In Group VII. the curve follows the normal curve rather closely until the rest is inserted after the seventh trial. Here there is a characteristic rise which immediately settles into a curve similar to the normal curve until the thirteenth trial is reached. From this time on the curve is lower than the normal and reaches the zero line six trials before the normal does. Again the indication would be that there is an immediate effect which is overcome by the next trial, after which no effect is noticeable for a period of five trials. Then the influence appears as a beneficial effect and continues throughout the subsequent trials. The curves for Group XI., where all of the records were used, for Groups III., and V., where only the high records were used, show both the immediate and delayed effects, identical in kind though not so pronounced in degree as is shown in Group I.

Series B. Rest Period of Twenty-four Hours

As was said in the introduction, a supplementary series of records was taken. The rest period for this series was twenty-four hours in length and three groups were employed. The groups are designated in a manner similar to those in the first series: Group III. had a twenty-four hour rest after the third trial; Group V. had the rest after the fifth trial; and Group IX. had the rest after the ninth trial. On account of lack of

time, these groups were not as large as those in Series A, there being only 15 individuals in each of the groups in Series B. The findings can best be considered as indicative rather than final. The results compared with the normal are found in Tables XV., XVI., and XVII.

TABLE XV

TRIAL TABLE

Group	Total	Average	Median	Stan. Dev.	P. E.
Normal	499	20	20	6.6	1.116
B–III	255	17	13	9.1	1.551
B–V	280	19	18	9.6	1.656
B–IX	360	24	18	11.6	2.023

TABLE XVI

TIME TABLE (SECONDS)

Group	Total	Average	Median	Stan. Dev.	P. E. Av.
Normal	18,023	751	744	306.6	43.1
B–III	9,487.5	632	493	346.3	59.828
B–V	7,278	685	578	363.2	62.579
B–IX	13,194.7	879	787	491.4	84.987

TABLE XVII

ERROR TABLE

Group	Initial Error	Total	Average	Median	Stan. Dev.	P. E. Av.
Normal	27	2,334	96.4	83.5	67.7	9.308
B–III	22	1,587	105.8	73	80.0	14.164
B–V	20	1,423	94.9	120	60.6	10.724
B–IX	24	1,695	113.0	125	77.7	13.759

Within the series itself the following results appear: The trials and time exhibit the same tendency; both the average and the median values for trials and time increase as the position of rest is inserted later in the learning; the median values only, in the error records, follow this same general direction.

If Series B be compared with the normal group, it will be seen that a rest period of twenty-four hours is beneficial when inserted early in the learning and detrimental when inserted

late. This statement holds true as far as the average and median values for time and trials are concerned, and also as far as the median values of the errors are concerned. The averages for the errors furnish one exception to the above tendency.

The distribution of trials, time, and errors as found in Tables XVIII., XIX. and XX. indicates the number of individuals obviously affected either detrimentally or beneficially. Where there is a detrimental effect it is restricted to a limited number; where the effect is beneficial its influence would appear to be one of massing of the whole group, but the number in the groups is too small for this last statement to be made with any marked degree of assurance.

TABLE XVIII

TRIAL SCATTER TABLE

Group	Below 10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55
Normal	1	3	7	4	6	3				
B-III	2	7	2	1	1	1		1		
B-V		6	4	2		2				
B-IX		2	6	1		2	1	2	1	

TABLE XIX

TIME SCATTER TABLE

Group	Below 500	500–1,000	1,001–1,500	1,501–2,000	2,001–2,500
Normal	5	17	1		
B-III	8	3	4		
B-V	5	6	3	1	
B-IX	3	7	3	2	

TABLE XX

ERROR SCATTER TABLE

Group	20–80	81–140	141–200	201–260	261–320	321–380	381–440	441–500	501–620	Above 620
Normal	6	11	3	3	1					
B-III	5	6	1	2		1				
B-V	5	2	6	2						
B-IX	4	2	6	1	2					

In comparing this series with Series A, it may be said: (1) the effect of the interpolation of rest varies in either series with the change of its position; (2) the variation differs in the two series. In Series A as the insertion of rest is moved away from the beginning of learning, the number of trials required for learning decreases until the optimal locus—after the seventh trial—is reached, after which the number of trials increases. In Series B, the number of trials required for learning increases steadily as the insertion is moved away from the early stages of learning. To illustrate these last statements: the lowest average time and average number of trials is found in Group III., at the beginning of learning, while the highest records for time and trial are found in Group IX. In Series A, Group III. has a trial record of 17; Group V. in the original series required 24 trials for learning, although Group V. in Series B required only 19 trials. In Series A, Group IX. is probably least affected by the interpolation of rest since the number of trials required for learning is identical with the number in the normal group; in Series B, Group IX. is the one most affected since the number of trials, 24, varies more from the normal, 20, than any of the groups in this series, and it is the only one detrimentally affected. (3) The optimal locus of the rest period of 24 hours is not identical with that found in Series A. (4) The results of this series are in accord with those of the first series in the following items: (*a*) the detrimental effect seems to be restricted to a limited number, (*b*) the beneficial effect is probably wide-spread and tends to result in massing all the individuals within a relatively restricted range, (*c*) the error record is not altogether a function of the interpolation of rest, but may be influenced by differences among the individuals themselves.

Discussion of Error Records

The fact that the relation of the variable of rest to the error values is considerably different from the relation of this variable to the values of time and of trials, is a problem which needs independent consideration. This difference may be explained in one of two ways: (1) the variation of the rest

period exerts a different effect upon errors than it exerts upon time and trials; or (2) the error records have been seriously affected by other chance factors.

The first point for consideration is the extent to which the error tendency is due to individual differences. A suggestion of such a possibility is found in the wide differences in the initial error records. It is known that errors and trials in maze learning vary independently to a large extent. A number of investigators using the maze have been convinced that there is no close correlation between the number of errors which an individual makes and the number of trials which he requires for learning. Additional support for this last statement is found in the observations of the writer. Sometimes the subject would appear so cautious and fearful of making a mistake that he would linger a long while, hardly moving the stylus. His error record would appear relatively low and his time and trial records high. Another type of individual would go rushing pell mell through the maze, making a large number of errors but consuming very little time in the doing. After a few trials the number of errors would decrease rather abruptly, and learning would be completed in a relatively short time and with few trials. These records would show rather rapid learning in spite of a large number of errors. It was further noticed that where the subject was moving the stylus with a considerable degree of rapidity he became aware of errors more quickly. In other words, if the error was made with considerable force, it was more impressive. Often a slow cautious individual would make the same few errors time after time and seemingly be unaware of making them. The entrance into the cul-de-sac was so gentle that no blocking or checking was noticed. These observations suggest the possibility that the seeming peculiarity of the error tendency may be due to an unequal distribution among groups of these few individuals who made a great many errors without their trial values being correspondingly affected.

The hypothesis presented above was tested in Groups V. and IX., the error records of which—it will be recalled from Table X.—deviate the most from the normal tendency. The

method used in order to secure the required information was a distribution of the individuals according to their error records, using only that portion of the records which had not been influenced by the interpolation of rest. For example, Table XV. shows the distribution of individuals of the Normal Group and of Group V. using the error records of only the first five trials, and Table XVI gives the distribution of the individuals of the Normal Group and of Group IX using the first nine trials.

TABLE XV

Group	Below 80	81–160	161–240	241–320	321–400	401–480	481–540
Normal	18	4	2				
V	14	3	3	2		1	1

TABLE XVI

Group	Below 50	51–100	101–150	151–200	201–250	251–300	301–350
Normal	9	7	5	2	1		
IX	3	8	4	5	2	1	1

It will be seen immediately that Group V. particularly, and Group IX. to a less degree, show considerable variability when compared to the normal. Group V. has four cases, and Group IX. two cases higher than the highest value of the Normal Group. Analysis of the records of these extreme cases brings out to a certain extent the influence of individual differences. The total errors of the four extreme cases in Group V. is 2,158. If this be taken from the total errors of the whole group, 4,971, the average error value for that group then becomes 140 where it had been 207. The average number of trials for Group V. after the elimination of these high records is practically unchanged, the value being 23 where it had been 24. If the two extreme cases of Group IX. be treated similarly, the average for this group becomes 133 where it had been 148. Substitution of these new averages for the original values for Groups V. and IX. tends to decrease, but does not entirely eliminate, the inconsistency of the error tendency. It is, therefore, probable that differences in individuals will not

explain entirely the deviations from the trials and time values which the errors manifest.

There is, then, the remaining possibility that variation of the rest period exerts a different effect upon errors from that which is exerted upon trials. There are several reasons which substantiate this assumption. In the first place, the error values should be consistent with the trial values only in so far as the errors are indirectly affected through the effort which the variation of the rest exerts upon the trials. In the second place, in so far as the variation of the position of rest affects errors directly, the situation is complicated by a number of factors:

1. Other things being equal, the effect on errors should decrease steadily as the rest period is moved toward the later stages of learning, for obviously the effect will be exerted for a decreasing number of trials.

2. The direct effect may be beneficial or detrimental according to the position of interpolation.

3. The direct effect upon errors will be influenced by the indirect effect through trials, and the error records will be affected as the number of trials is increased and decreased.

For these reasons it is evident that there is no justification for assuming that variation of rest will exert the same effect upon errors as upon trials.

General Summary

I. When the rest period is forty-eight hours in length, it may be concluded that:

1. In learning the stylus maze which was used in this investigation, the optimal locus of a rest period of forty-eight hours for the criteria of time and trials is at the end of the seventh trial.

2. The beneficial effect caused by the interpolation of rest after the seventh trial is wide-spread, influencing all of the individuals in the group.

3. Insertion of rest at any stage in the learning other than at the end of the seventh trial is detrimental. If this insertion be early in the learning, the number of individuals known to be

influenced is limited, but the detriment for these is considerable. If the rest be inserted after the optimal location is passed, all of the individuals seem to be detrimentally affected, but only to a slight degree.

4. The interpolation of a rest period is always followed by an immediate effect which is detrimental, but which apparently is of short duration. Approximately five trials after this immediate effect, there appears a delayed effect which is beneficial or detrimental according to the stage of interpolation.

II. When the rest period is twenty-four hours in length, it may be concluded that:

1. The optimal locus of a rest period of twenty-four hours is in the early stages of learning,—between the first and the fourth trials.

2. The only detrimental effect noticeable in this series is when rest is interpolated after the ninth trial.

3. On account of the small number of individuals in the twenty-four hour series, the results can best be thought of as suggestive and as needing further confirmation.

III. *Relation of this Investigation to the General Topic of the Optimal Distribution of Effort.*—From the results of this investigation, it is evident that the value of rest varies with the position of interpolation and with the length of the rest period. To illustrate: (1) in both series the effect varied from one of detriment to one of a beneficial character as the position of interpolation was varied; (2) in comparing the two series, it is evident that the optimal position differed with the length of the rest period.

These results further indicate that the usual procedure of regularly inserting the same length of rest throughout the period of learning will not determine the optimal distribution of rest. For example, an interval of twenty-four hours was found to be most effective in the early stages of learning, while a longer interval was beneficial at a later stage. It would appear, therefore, that the rest period should not be constant for different stages of learning. It is not, however, to be concluded from the facts brought out in this investigation that

the interpolation of a short rest period at the beginning of learning, and a later interpolation of a longer rest interval will necessarily be beneficial. The combination of two interpolations, either of which is beneficial, might give different results.

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THE LAW OF ORIENTATION IN STEREOSCOPY[1]

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The main principles of stereoscopy as known experimentally with plane pictures as subject matter have been fairly well understood since the days of Wheatstone and Brewster. Thus it is common knowledge that two essential conditions for obtaining the full stereoscopic effect are: First, that there must be dissimilar pictures registered from two discrete locations and singly presented, one to one eye and the other to the other. And secondly, that when fixating analogous points in these pictures the eyes must be converged to that optimum extent which for the given individual will give a unitary image having full solidity.

In experimental stereoscopy these two conditions, single presentation of dissimilar pictures and optimum convergence of the eyes, can be met by a variety of instrumental means, the most familiar being the lenticular stereoscope of Brewster. This serviceable instrument has the disadvantage, however, of limiting one to small pictures viewed at close range. These limitations of the prismatic stereoscope have recently been overcome in the Toronto laboratory through a special type of stereoscope with flexible prisms which will enable one to fuse at will juxtaposed pictures of any size and shown at any distance from the observer.[2] The facility of experimental control thus obtained has brought to light some points about stereoscopy which I believe are not generally appreciated. With one of these this paper will deal.

The point at issue may be variously stated. In one form it is the question whether a pair of stereoscopic pictures are

[1] Presented in part before the American Psychological Association, Washington, D. C., December 28th, 1924.

[2] The flexible-prism stereoscope has been described in this JOURNAL, Vol. VIII. No. 2, Apr., 1925.

ocularly specific or ocularly indifferent. The regular procedure for obtaining full relief with stereoscopic pictures is for the right hand view to be given to the right eye and the left to the left, whereas if the pictures be given to the opposite eyes the fusion is imperfect and the depth more or less reversed in character. From this it might and apparently often is assumed that in order to obtain natural depth from a pair of stereoscopic pictures a particular one of the pair must always be presented to a particular eye. As a general principle this assumption is unwarranted. The fact is that full natural depth can always be obtained whichever picture is shown to whichever eye. In other words stereoscopic pictures are ocularly indifferent provided that they be orientated in a particular manner when they are being fused. Our aim is to illustrate and to define in general the requirements of orientation that condition the perception of optimum depth.

The experimental approach to this question may be presented as follows: If three-dimensional subject matter [1] be photographed with a binocular camera held level in the ordinary way, the printed pictures, *e.g.*, Fig. 1, *A* and *B*, when shown to the corresponding sides in a stereoscope will, of course, fuse effectively, whereas if they be transposed to the opposite eyes they will not. If now the same objective subject matter be again photographed in this case with the base of the camera tilted upward 60 deg. at the right and if the resultant pictures A_1 and B_1 be shown side by side as before in a stereoscope, what will the eyes make of them? Or again as an extreme instance if the camera be tilted so that the two lenses are vertical instead of horizontal will the pictures so obtained, *i.e.*, *A*2 and *B*2, fuse with depth when observed side by side in a stereoscope? If they will it is clear that rightness and leftness of the photographic aspects are not an essential condition for obtaining the solidity effect

[1] Our subject matter as illustrated in Fig. 1 consisted of an ordinary wire waste paper basket photographed at 2 meters distance against a white ground at 2½ meters, the contents of the basket being arranged to exclude the more obvious clues to perspective. A binocular 5 x 7 in. camera was used with inter-lens distance of 8 cm. The experiment has been duplicated and the results verified using exterior subject matter involving various distances.

as this distinction is wholly inapplicable to pictures registered from positions that are vertical.

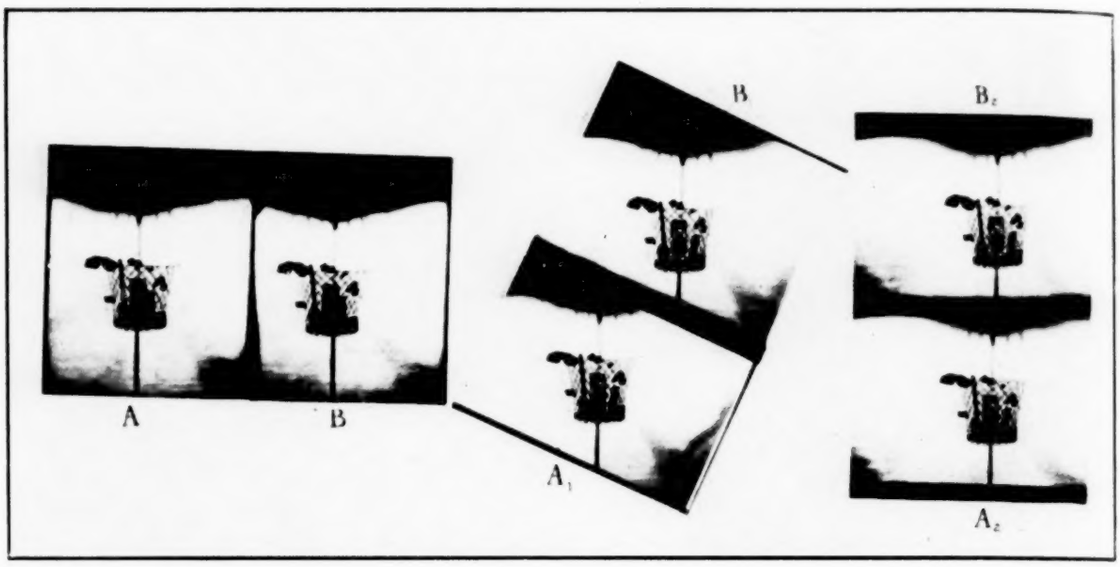

FIG. 1. Types of registration. Registration base of A and B is horizontal, of A_1 and B_1 is at 60 degrees, of A_2 and B_2 at 90 degrees.

In order to discuss the findings in such cases it is convenient to make use of three fundamental conceptions, (1) the *registration base* of the pictures, (2) the *observation base* of the eyes, and (3) the *orientation* of the pictures. To define these conceptions: The registration base is the hypothetical straight line joining the discrete locations from which each of a given pair of stereoscopic pictures is photographically registered. When using a binocular camera this may be considered as the line joining the two lenses. Let the registration base be termed R; in Fig. 2 it is inclined upward toward the right and therefore the registered pictures would be analogous to A_1 and B_1 in Fig. 1 above.

Similarly the observation base is the hypothetical line joining the eyes when a pair of pictures are being observed for stereoscopic purposes; it is simply the interocular line and is pertinent of observation conditions but has no immediate connection with registration conditions. Let O in Fig. 2 represent the direction of the observation base of a person who is observing in a stereoscope pictures originally taken on a base such as R.

Only the relative direction of these bases *O* and *R* and not the absolute registration distance or the absolute interocular distance need here concern us. The actual interocular

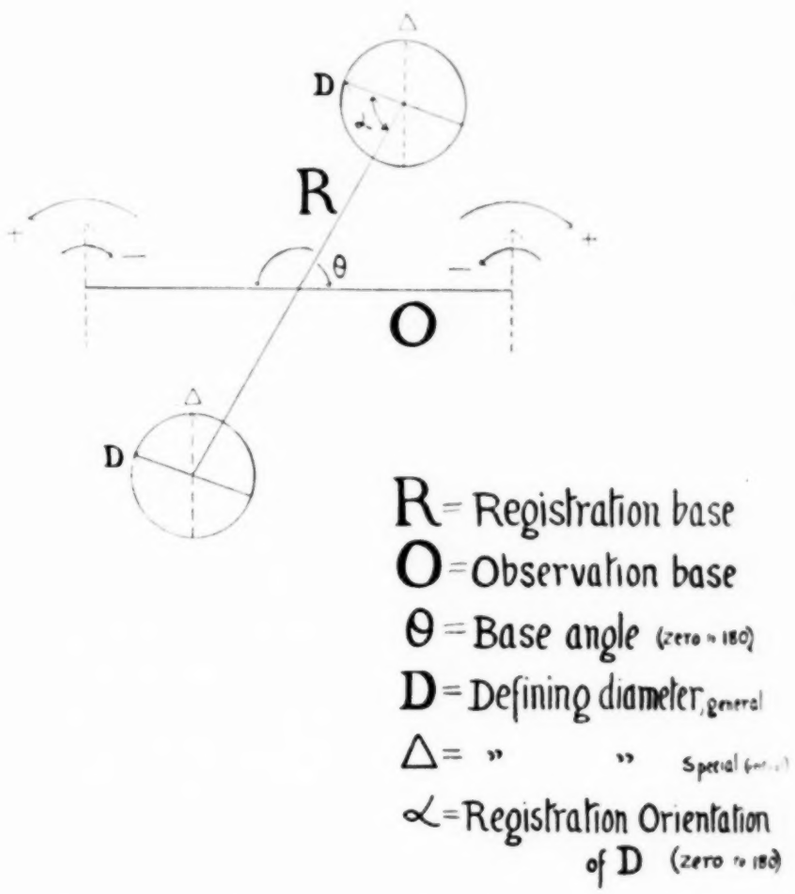

FIG. 2. Terminology of orientation. *R*, registration base; *O*, observation base; Θ, base angle of any size, zero to 180 degrees; Δ, special defining diameter of pictures with known objective orientation such as the vertical of nature; *D*, general defining diameter of pictures; α, registration orientation of *D* to *R*, size zero to 180 degrees. Upon whichever side of *R* the base angle Θ is taken let α be upon the opposite side.

distance on *O* will vary, of course, in the case of youthful observers (and also among adult individuals) over a range of from about 45 to 70 mm. And likewise the actual registration distance on *R* may differ enormously in stereoscopy depending upon the type of objective matter from merely a fraction of an inch to many miles, but ordinarily it is selected to approximate the average adult interocular distance.

When a binocular camera is operated with the registration base horizontal and when the observation base is also hori-

zontal in viewing the pictures, it may be accepted that these bases coincide in direction. Although this is a circumstance that obtains almost universally in stereoscopic photography, it is, of course, a special circumstance and not necessarily the case. In general, as our instances in Fig. 1 suggest, the direction of these bases may incline one to the other any angular amount. Let the angular distance between the bases *R* and *O*, *i.e.*, the angle through which *R* would theoretically have to be revolved clockwise or counterclockwise in order that it coincide in direction with *O* be termed the *Base Angle* or Θ, see Fig. 2. While, therefore, the Base Angle is ordinarily zero degrees, actually it may have any value between the limits of zero and 180 degrees.

The third and most important conception is the orientation of the pictures. In order to make clear the sense in which we wish to use this conception in stereoscopy certain points of principle and of procedure may here be mentioned. In the first place a distinction is to be drawn between the orientation which pictures receive when they are taken ('registration orientation'), and that which may be given such pictures when they are being observed in a stereoscope ('observation orientation'). Further, for any particular pair of stereoscopic pictures the former is a constant rather than a variable factor. That is to say the original subject matter in nature will necessarily have some definite and definable orientation and this will be directly registered in the pictures however the camera be held. On the other hand when a pair of pictures comes to be viewed in a stereoscope one can readily vary their orientation by manipulation of the pictures (in a manner to be described below), and the effect of this control upon the perceived quality of depth can then be observed. In brief our procedure will be to relate the facts of orientation under the two circumstances above mentioned, and meanwhile we are suggesting (*a*) that any particular pair of stereoscopic pictures have of necessity some given 'registration orientation,' (*b*) that the 'observation orientation' of a pair of pictures may be varied experimentally, and finally (*c*) that a differential value of (*b*) can be determined on the

basis of an immediate judgment of depth by the observer. From our standpoint, therefore, orientation should be defined in a way that will best enable one to measure and compare the orientation which pictures have as registered with that which must be given them in a stereoscope in order that the best quality of depth may be observed.

In the broadest sense orientation always involves spatial factors both internal to and external to the datum which is said to have orientation. Consequently to define the orientation of a picture, either as registered or as observed, will require having (1) some systematic way of delineating spatial differentiation within the picture (2) some base of reference without the picture, and (3) some consistent and unambiguous mode of expressing the spatial relation of these internal and external factors. No doubt these requirements could be met in a variety of ways and the plan we are to adopt is certainly not free from difficulty; it has, however, proved convenient in practice. To mention one or two difficulties: First, in defining the orientation of a picture with respect to a selected external base of reference we shall not be concerned to define the orientation of the latter, *i.e.*, with respect to some larger system of things. In any absolute sense this latter issue is incapable of final solution, and for practical purposes the orientation of the reference factor can safely be taken as given without risk of ambiguity arising from this assumption. Secondly, the way in which spatial relations should be characterized, in order to secure clear and uniform treatment, presents some difficulty. There are, of course, many conventions for the discrimination of spatial relations, some more purely personal in character and others more purely objective, for example, right and left, clock directions, compass directions, gravitational directions (vertical and horizontal) etc. Possibly no one of these conventions would in itself suffice for the treatment of orientation in all the circumstances that might arise in stereoscopy. Gravitational reference, however, is easily understood and will be found adequate for the majority of cases (except, for example, in aerial photography). We shall therefore employ gravitational reference as far as

possible, but in addition we shall aim at a more general treatment of orientation which will be applicable for all types of cases. The latter plan will utilize R and O as bases of reference and the spatial relationship of the pictures thereto will be geometrically (*i.e.*, angularly) expressed.

To turn now to the definition of registration orientation. Let us suppose that the objective matter to be photographed is an ordinary exterior setting such as a street scene and that a binocular camera is used with the registration base, R, not necessarily horizontal. The registered pictures, though stereoscopically dissimilar, will in any event each be a recognizable reproduction of the scene in question. Instead, however, of considering each picture as a whole our first problem is to devise some simple scheme of spatial differentiation within the pictures which will serve to designate their orientation. For this purpose some conspicuous feature in the objective material to be photographed can be selected to serve as a defining diameter in the pictures—preferably some objective feature which will reproduce in the picture as approximately a straight line. The selected objective feature will necessarily register in the body of each picture and these straight-line reproductions will appear as corresponding *parallel diameters* in the two dissimilar pictures no matter how the camera be held nor in what direction the chosen diameter may lie in each picture. A diameter having been selected, to define its orientation will define the orientation of the picture in which it belongs; moreover, as the selected diameters in stereoscopic pictures always register parallel, a pair of pictures may be accepted as having identical orientation.

The second requirement of definition, as we have seen, is to have a base of reference that is external to the picture and that has orientation in its own right. In the selection of a base of reference in stereoscopy two types of circumstance may arise, namely, cases where the objective subject matter has features with obvious gravitational significance, *e.g.*, vertical reference as a tree-trunk, or horizontal reference as the sky-line, etc.; and on the other hand cases where recognizable orientation in a gravitational sense is wanting in the

objective data as may be the case, for instance, when it is viewed directly from above.

The first type of case would be exemplified in our supposed street scene and indeed in most terrestial photography. Here it is possible to short-circuit the process of definition by selecting as defining diameter not any convenient feature of the picture but one that represents some known gravitational orientation such for example as the vertical of nature, *e.g.*, the corner of a house, etc. Recognizable gravitational orientation will thus be characteristic of the defining diameter as registered, and this property of a diameter can then be utilized as a base of reference from which to measure any new orientation that may be given the pictures experimentally when they are being stereostopically observed. In this special type of case the characteristic orientation with which we deliberately endow the selected diameter will constitute the registration orientation of the pictures. Hereafter a diameter with known gravitational orientation will be termed Δ. In Fig. 2, for example, there is a registered Δ diameter which is gravitationally vertical; on the contrary, if the sky-line had been selected as a defining feature, then our Δ diameter would have been horizontal.

The second and more basic type of circumstance is where, as in aërial photography, an objective feature with known orientation may not be available as a diameter, in which case a railroad or other like feature of topography must be accepted whose orientation is unknown in terms of gravitational or of compass directions and is definable only in terms of its angular relation to the registration base, R.[1] In principle this circumstance constitutes a general case. A diameter of this type will be termed D in distinction from the type Δ, as in Fig. 2. In the general case the selected diameter will define orientation directly in terms of the angle that D makes with R. For either registered picture let this angle between

[1] To utilize R as an external base of reference, of course, implies that the orientation of R is known. Although it may happen in stereoscopy that this property of R is not immediately known, our procedure is not thereby invalidated in as much as R can in that event be conceived in relation to another factor, O, whose orientation can always be accepted as given.

R and D on the side of R opposite to the base angle, Θ, be known as the *registration orientation*, and be designated as α. In practice the registration orientation of pictures may then have any angular value from zero to 180 degrees.

Turning next to the orientation of pictures when they are being stereoscopically observed, we have thus far the following conventions: a registration base R, an observation base O, a base angle Θ, and parallel diameters that define registration orientation, either in some specific objective sense or angularly in relation to R. In experimental stereoscopy there is, of course, no immediate spatial connection between the actual registering of pictures and the actual observing of them, this relationship being merely a conceptual one.[1] It is helpful, however, to discuss the observation of pictures as though there were an actual geometrical connection between registration and observation. Thus instead of allowing that pictures registered upon any base R can at one's convenience be presented upon any observation base with either picture to either eye, one can conceive this as being accomplished by revolving R with its pictures through the base angle to coincide with the base, O. In this way Fig. 3 illustrates that R may be regarded as revolving in one direction (*e.g.*, clockwise) to present the pictures each to a particular eye, or in the other direction to take them to the opposite eyes. And our convention of angle nomenclature as regards Θ and α may be applied with either mode of presentation.

When pictures are being presented and fused in a stereoscope their orientation is, of course, in no sense predetermined and can be experimentally controlled through 360 degrees by synchronously turning the individual pictures clockwise or

[1] This can be made clear by stating a typical problem. If one is handed a pair of stereoscopically dissimilar pictures on separate mountings and is asked to determine the details regarding their registration conditions, this can be done through empirical stereoscopic observation supplemented by conceptual knowledge of the relation that obtains in general between the conditions of registration and those of observation. For this problem one knows O (*i.e.*, the direction of the observation base one employs when fusing the pictures), and also one can select some suitable D from the pictures; it is then possible to determine merely by stereoscopic experimentation what the base angle (Θ) and the registration orientation (α) were, without having had anything to do with the actual registering of the pictures.

counterclockwise in the plane of the face, always maintaining the defining diameters parallel. Fig. 4 illustrates the mechanism used for this control. As shown, the observation base

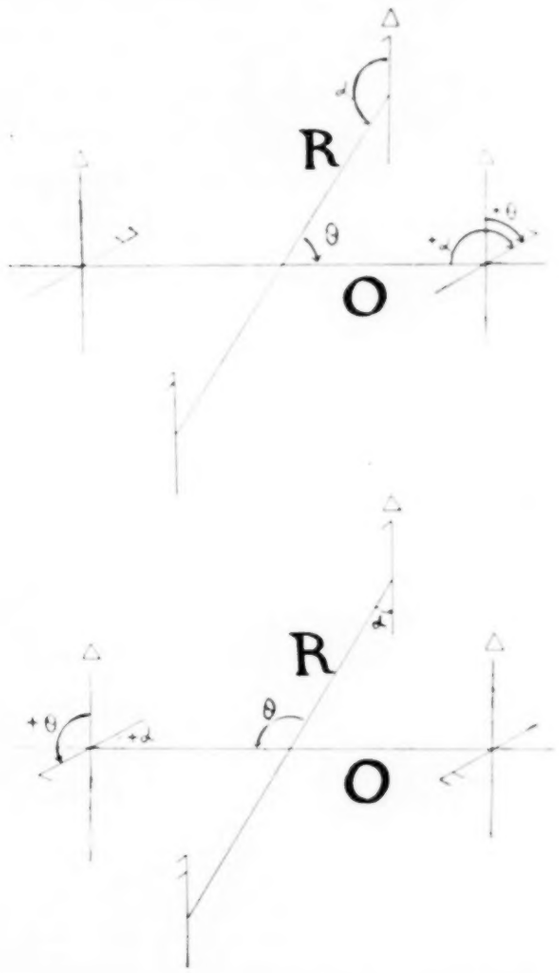

FIG. 3. Observation orientation. Upper diagram shows that when dissimilar pictures are registered on *R* with vertical Δ diameters and are presented on *O* with the single barbed picture to the right eye they must be revolved *positively* Θ degrees from the origin Δ, or α degrees from the origin *O*. In the lower diagram when the pictures are presented to the opposite eyes the proper orientation is again stated as Δ + Θ degrees when reckoned from Δ or as + α degrees from *O*.

is horizontal; but as *O* may on occasion be a variable the findings should be formulated as not dependent upon any particular ocular posture.

When dissimilar pictures are thus controlled during observation in order that their orientation may be varied with respect to the observer, it is found that the quality of perceived depth depends upon the new orientation thus given to

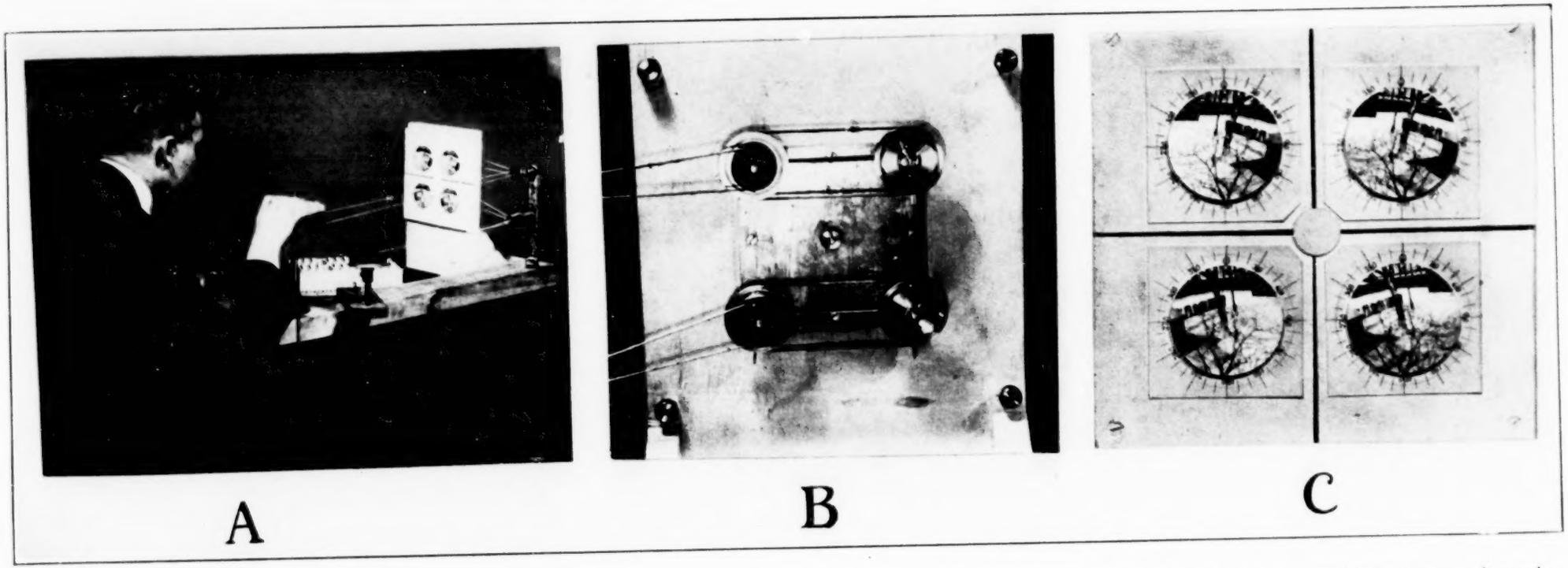

FIG. 4. Apparatus for viewing and orientating stereoscopic pictures, namely, (*A*) flexible prism stereoscope and mechanism for controlling picture orientation, (*B*) rear of control mechanism, (*C*) typical experimental views, the upper pair printed in obverse and the lower in reverse.

the pictures and is independent of the observer's posture as well as of which picture is to which eye. Let that orientation of the pictures which gives optimum depth as judged by the observer be termed the *observation orientation*. The reading for this is obtainable from the circular position empirically given to the diameters and this position has to be computed systematically from a suitable origin, for example, from Δ in cases where the diameter has characteristic orientation in nature, or, in the more general case from O which is necessarily known with respect to the pictures at the time they are being observed.

A final convention is then required, namely, to designate the clock-sense direction in which a picture diameter is being orientated with respect to the origin Δ or O. If we are content to conceive the pictures as being presented to the eyes (either to each) by revolving R clockwise or counter-clockwise through a base angle to coincide with O, then it will be convenient to consider the direction of picture orientation *positive* when it is in the same circular direction as is hypothecated of R, whereas it is *negative* when contrary thereto. The sign for the direction of observation orientation is thus adapted to the manner of presentation as regards which picture goes to which eye, as is indicated of the upper registered picture in Figs. 2 and 3.

Turning now to the results, typical findings for observation orientation may be instanced which will reveal the general principle.

1. Take pictures that are registered with a base angle of 60 degrees and that have a Δ diameter which is vertical as Fig. 1 A_1 and B_1 and again Fig. 2. Let these be presented on O in vertical orientation, B_1 to the right eye and A_1 to the left, conceiving this to be achieved by revolving R clockwise through the Θ angle of 60 degrees. Seen with a stereoscope they here fuse as unitary but show little if any depth. Optimum depth, however, is perceived when they are orientated from the vertical 60 degrees in the clockwise direction as indicated in the upper diagram of Fig. 3.[1] Let the pictures

[1] The quality of depth for other orientation positions is of no less interest and

now be transposed, B_1 being shown to the left eye with diameter vertical and A_1 to the right, which would be achieved were R revolved counterclockwise to O through the θ angle of 120 degrees. They then fuse but appear flat, nevertheless it turns out that optimum depth is obtainable at a point 120 degrees counterclockwise from the vertical, as in the lower diagram of Fig. 3. In each case the orientation is positive with respect of Δ and is equal in amount to the base angle.

2. Again take pictures registered one directly above the other, base angle 90 degrees, and with a vertical diameter, as Fig. 1 A_2 and B_2. Presented on O with B_2 to the right eye, *i.e.*, by revolving R clockwise 90 degrees, they fuse when the diameters are vertical but are flat, whereas full depth is obtained when they are rotated clockwise 90 degrees from the vertical. And transposing B_2 to the left eye, as by revolving R counterclockwise 90 degrees, they give perfect depth when orientated 90 degrees counterclockwise, although with vertical orientation they are flat. Thus for this registration as for that at 60 degrees the orientation from Δ is positive and equal to the base angle.

3. Or again, take pictures registered with the camera horizontal as in Fig. 1 A and B. The base angle is here zero degrees and the diameters vertical. Presenting these with picture B to the right eye would require no revolution of R and likewise no change from vertical orientation is required to obtain the full solidity effect. This circumstance represents the common practice in commercial stereoscopy; it is, however, merely a particular case of the general principle with which we are concerned. Further, if B be given to the left eye, which is equivalent to R being revolved through a θ angle of 180 degrees, then the pictures show perfect depth if revolved from the vertical a like amount (180 degrees), *i.e.*, to be upside down. And this circumstance is familiar to us all from the fact that an ordinary binocular slide in a stereoscope is as depthful upside down as right side up because in

will be reported upon later, our present object being to derive the rule for predicting the orientation that gives *optimum* depth for pictures howsoever registered and howsoever presented to the respective eyes.

the former position the pictures are transposed to the opposite eyes but at the same time are given the required adjustment of orientation.

The above instances are typical of other possible registration positions and they show that in stereoscopy the eyes are indifferent not merely to which picture they receive but also to the registration conditions of the pictures that are presented. In other words an observation orientation giving optimum depth exists for all stereoscopically dissimilar pictures whatever be the mode of registration and of presentation. It remains to formulate the rule for predicting this orientation position in terms of the conceptions we have introduced.

To deal first with the type of special case wherein the pictures have a Δ diameter with known objective orientation. By induction from the cases cited and from other registration conditions [1] the observation orientation for optimum depth is:

$$\Delta + \Theta \text{ degrees.}$$

For all such cases the rule may be stated as follows:

Stereoscopic pictures presented with their natural orientation and shown to either eye will always fuse with optimum depth when rotated positively an amount equivalent to the base angle.

For the general case wherein observation orientation is reckoned from the observation base rather than from Δ, the formula for orientation simply is:

$$+ \alpha \text{ degrees.}$$

The general statement therefore is:

Stereoscopic pictures will always fuse with optimum depth if given the same orientation upon the observation base as they had upon their registration base.

Because the formula for the general case and that for the special case (where Δ orientation is known) are alternative quantitative expressions for the same orientation location, it follows that

$$\Delta + \Theta = \alpha,$$

[1] Verification of the rule by four subjects was experimentally obtained with pictures registered with the following base angle: 0, 22½, 30, 45, 60, 67½, 90, 110, 130 and 150 degrees.

when these expressions are measured angularly from a common origin, viz., *O*. This will be evident from geometrical considerations and from our conventions of signs, as illustrated in Fig. 3 above.

It will also be evident to the reader that the generalization which has been given regarding the orientation for full depth merely expresses the fact of a requirement that is more or less obvious. This fact is that because in daily life visual perception of depth is not dependent upon posture, therefore, in experimental stereoscopy, if one's observation base were always to coincide with the photographic registration base no adjustment of the pictures would ever be required, *i.e.*, one would see depth immediately upon fusing the pictures as readily as one would upon viewing the original in nature. The point is that for purposes of experimental stereoscopy one does not need to adjust one's posture to conform with the original registration conditions because the latter can more easily be reconstructed in conformity with an observer's posture, *i.e.*, with any *O;* and this is all that the generalization expresses. Or, to put the matter in terms of our convention of picture presentation, supposing the pictures to be fixed in their original orientation upon *R* and that they could then be presented either to either eye merely by revolving *R* through the base angle to coincide with the observation base, they would then have the correct orientation for the observation of depth. In this sense the principle of orientation as thus far expounded might fairly be regarded as a truism even though the statement of it were not common knowledge; but the principle is capable of an important extension which is perhaps less open to the charge of being obvious.

This extension has to do with the observation orientation required of stereoscopic pictures when they are photographically printed in *reverse* instead of in *obverse* (their natural form), *i.e.*, when all the detail in each picture is laterally inverted as in a mirror.[1] If the experiments previously discussed of obverse prints be repeated with the subject matter printed in reverse it will be found that, to whichever

[1] In Fig. 4 the upper pair of pictures are printed in obverse and the lower pair are from the same negatives printed in reverse.

of the eyes the pictures are now shown, they can always be fused with optimum mirror-image depth if properly orientated. It turns out, however, (1) that the orientation required for pictures in reverse is significantly different from that for pictures in obverse, (2) that the difference between these readings is consistently a given function of the base angle, and (3) that therefore the orientation for pictures printed in reverse can be generalized in terms of the conceptions and conventions already outlined.

In Fig. V. the difference in observation orientation for the two modes of printing is illustrated geometrically from empirical determinations for typical registration positions.[1] The pictures have a vertical Δ diameter, the dissimilar views are distinguished by the single and double barbing of the diameters, the form of printing is indicated by the side of the diameter to which the barbing points and also by the fact that the observation orientation reading for pictures in obverse is shown by a broken diameter and that for pictures in reverse by a solid diameter. Readings are given only for that circumstance in which the picture with single barbed diameter is presented to the right eye, the corresponding readings when the pictures are transposed to the opposite eyes being in each instance 180 degrees removed from those here indicated.

Consideration of these and analogous data for other registration positions will reveal that a definable relationship regularly obtains between the observation orientation for pictures printed in reverse and in obverse, namely, that the former is equal to the latter increased algebraically by the complement of double the base angle (or alternatively, by double the supplement of that angle). As regards direction of orientation this increment may be dealt with as positive and expressed as $\Pi - 2\Theta$.

This being the case, two expressions for the orientation of pictures printed in reverse can immediately be derived by adding $\Pi - 2\Theta$ to each of the two expressions we already

[1] Only the results for six registration bases are shown with base angles of 0, 30, 60, 90, 110 and 150 degrees respectively.

have for the orientation of pictures in obverse, the derived expressions being in terms of Δ and Θ and of α and Θ respectively. Thus for cases with a Δ diameter we have $(\Delta + \Theta) + (\Pi - 2\Theta)$ or $\Delta + \Pi - \Theta$. And for the general case we

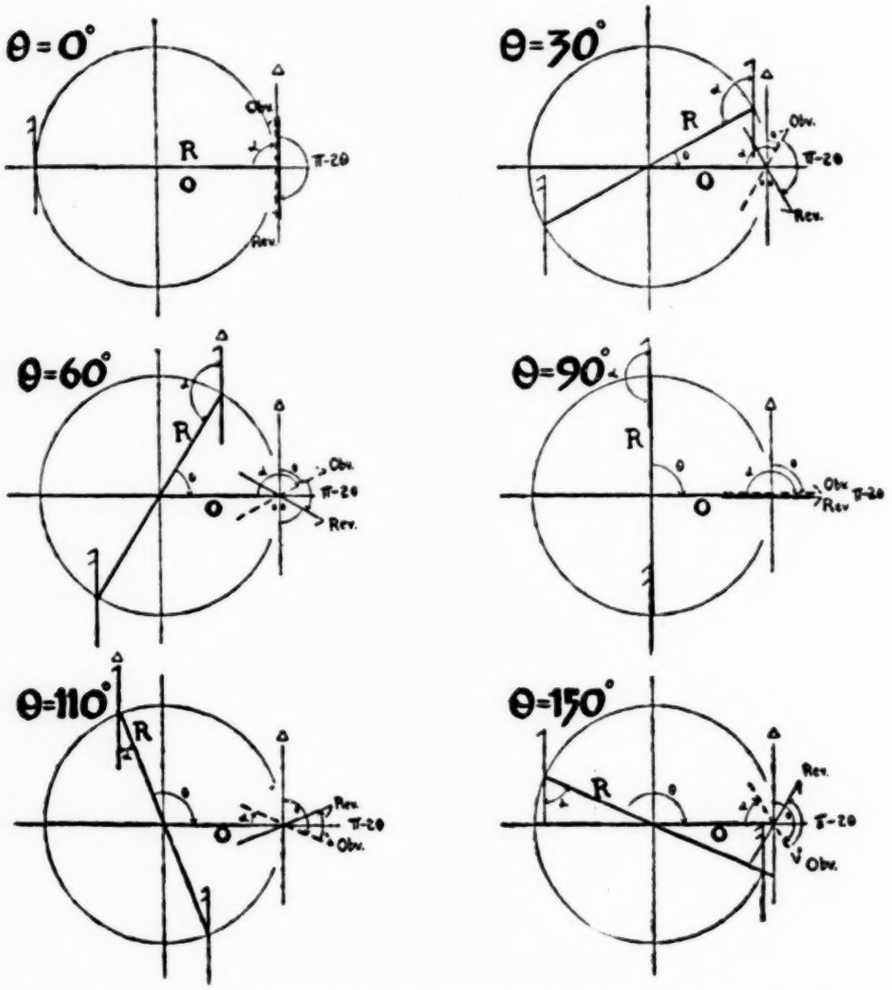

FIG. 5. Observation orientation of stereoscopic pictures printed in obverse and in reverse.

have simply $\alpha + (\Pi - 2\Theta)$. Still a third expression for the orientation of pictures in reverse may be had in terms of Δ and α by substituting for Θ in either of these latter expressions, namely, from the equation $\Delta + \Theta = \alpha$ as previously given. Thus from $\Delta + \Pi - \Theta$ we get $\Delta + \Pi - (\alpha - \Delta)$ or $2\Delta + \Pi - \alpha$.

Summarizing then, for both forms of printing we have as the observation orientation of stereoscopic pictures:

A. Printed in obverse

$\Delta + \Theta$ ..... (1) Special case
or α ..... (2) General case

B. Printed in reverse

$\Delta + \Pi - \Theta$ ..... (3) Special case
or $2\Delta + \Pi - \alpha$ ..... (4) " "
or $\alpha + \Pi - 2\Theta$ ..... (5) General case

In practical problems of stereoscopy the formula to be chosen from the above will depend upon what facts are known and what are required. On the other hand the statement of principle may preferably be in terms of the general case. The general law of orientation [1] for pictures printed in the obverse or in the reverse form therefore is:

Stereoscopic pictures registered with any orientation and printed in obverse will always fuse with optimum depth when given this orientation on the observation base, and if printed in reverse they will always fuse with optimum mirror-image depth when given this orientation increased by the complement of double the base angle.

One advantage of stating and applying this law in respect of both forms of printing is that the basic facts of registration can thereby be directly determined from the observation of any pair of stereoscopic pictures. Thus, if two empirical readings of observation orientation be made, one with the pictures in obverse and the other with them printed in reverse, the angular difference between these readings (being always $180 - 2\Theta$ degrees) will give the size of the base angle. Further the registration orientation, α, will be known as obtained from the reading in obverse, and likewise O is known from the circumstances of observation. It is thus possible

[1] Experimentally there is a *range* rather than a point of observation orientation because of the fact that the eyes have a certain tolerance for fusing pictures with full depth even when their orientation deviates somewhat from that prescribed by rule. This orientation tolerance is a matter of both theoretical and practical interest and will be dealt with subsequently. The point of observation orientation in terms of which our findings have been stated throughout is simply the mid-point of the range of orientation which gives equally good depth. The empirical deviation of this mid-point from its theoretical position as expressed by the general law we have found to be consistently small with practised observers.

to ascertain the conditions of registration in detail; or conversely when given the facts of registration one can predict the orientation required of the pictures for purposes of stereoscopy.

Finally, it may be concluded that strictly speaking the concepts of right and left or of vertical and horizontal have no intrinsic significance in stereoscopy either as regards the registering of the pictures, the form of printing obverse or reverse, the eyes to which they shall be presented or the postural orientation of the observer. The concepts of right and left, etc., are merely convenient in the discussion of special cases where some of the orientation factors are specifically conditioned as they are in a gravitational sense, for instance, in a theatre where the pictures must be presented in vertical orientation and the observation base of spectators is assumed to be horizontal. Then a particular picture must be given to a particular eye. Our purpose has been to show that in experimental stereoscopy the requirements of orientation can be formulated for the general case as readily as for any.

EFFECT OF SUGGESTION AND TOBACCO ON PULSE RATE AND BLOOD PRESSURE

BY ROY M. DORCUS

From the Psychological Laboratory of the Johns Hopkins University

This investigation was undertaken to answer a question raised by Bates (1) and by Hull (2). In determining what effect tobacco has on pulse rate and blood pressure, what part of an increase or decrease is attributable to physiological causes and what part to psychological causes?

Hull and O'Shea (3) report work carried on in a rather careful manner, although there are in their work some assumptions which can hardly be justified in light of psychological findings and their own statements. The results which they obtained are quite interesting and are partly substantiated by the results obtained in this investigation.

The specific point for consideration in this article is the results obtained by Hull on the effect of tobacco on pulse rate. To make this clearer, a resume of his technique is necessary. In his experiment, the effect of tobacco on certain mental and physiological conditions, including pulse rate, was studied on 18 subjects. On certain days, the subjects smoked tobacco in an ordinary pipe and on certain other days, the subjects smoked an especially constructed pipe of the same external appearance through which they drew only heated air. Every day the subject was blindfolded and on the control days (days on which no tobacco was smoked) the experimenter smoked beside the subject. The whole 'set' was designed to convince the reactor that he was smoking, even on the control days, and the experimenter maintains that such was the case.

In his instructions to the subjects, Hull says: "Accordingly (it was explained) it was imperative that the subject should give the same conscientious application to the mental tests throughout the experimental period. It was pointed out with

great earnestness that the success of the entire undertaking depended upon this. If, for example, there should be any letting down of the subject's efforts after smoking (it was explained), this would decrease the score at that point and would falsely be taken as an evil effect of the tobacco, thus completely invalidating the experiment." If this statement is to be taken literally, it would appear that the 'set' for the reactor is one that would give him the idea that there is some deleterious effect from tobacco. If the attitude or 'set' of the reactor was one in which he wanted to show the deleterious effect of smoking, he would only have to let down in his work on the smoking days; if his 'set' was such that he believed the effects were beneficial, he might voluntarily or involuntarily work slightly under his average capacity on non-smoking days or exert an extra effort on the smoking days to produce the condition which would fulfill the requirements for his 'set.'

On non-smoking days, the experimenter smoked while the subject was inhaling only heated air. It seems therefore that even on 'non-smoking' days the subject would then be inhaling tobacco smoke, although it would be more diluted than when the subject himself smoked.

Hull holds that, since we can taste only sweet, sour, bitter and salt, the sensations derived from tobacco are all olfactory. This may or may not be true. However, there are certain tactual sensations which arise in the mouth, and a certain astringency (perhaps tactual, perhaps chemical) which also appears there. Certainly, many persons notice an 'after taste' from smoking which lasts for a considerable time after one has stopped smoking, and which is neither salt, sweet, bitter nor sour.

Hull admits that in one case, the subject could not be fooled by the control smoking but attributes this to the fact that he saw the pipe. If the procedure were adequate, the matter of seeing the pipe on one occasion should not be sufficient to allow the subject to detect, when blindfolded, the difference between smoking and non-smoking days.

In this experiment, three subjects were tested for twelve

days each. The subjects, upon reaching the laboratory, were seated comfortably in a reclining chair for a period of about fifteen minutes. At the expiration of that time, blood pressure readings and pulse rate count were taken. Systolic and diastolic pressure and pulse rate were then taken once every three minutes for one hour and fifteen minutes. The total working time (exclusive of the preliminary rest period) was divided into five fifteen-minute periods. During the first fifteen minutes the subject rested quietly and did nothing except indulge in ordinary topics of conversation; in the second period the subject was hypnotized; in the third period the subject was given an unlighted cigarette and was told that he was to smoke the cigarette; in the fourth period the subject was given a lighted cigarette and told to smoke it and in the fifth period, smoking was discontinued. This routine was carried on for twelve days. The only deviation being that on certain days, determined by chance, the procedure in the third and fourth periods was reversed. On some of these days the subject received a lighted cigarette in the third period followed by an unlighted cigarette in the fourth period; on other days, the subject, in the third period, received either a lighted or an unlighted cigarette and smoking was discontinued at the end of the third period instead of at the end of the fourth period. These shifts in procedure were introduced as checks to determine what variations might be produced thereby.

The suggestions to the subjects were carefully controlled and all the other conditions were kept as uniform as possible. It must be remembered that in work of this nature it is rather difficult to secure subjects for prolonged work, and it is still more difficult to find suitable subjects. The subjects were placed in a rather deep hypnotic condition and were told that they would be free from disturbances, and that they would remain in that condition until they were awakened by the experimenter. They were also prohibited from opening their eyes. When told to smoke, they were given the cigarettes by the experimenter and the process of lighting it was carried out, except that the match was not applied to the

cigarette in the non-smoking period. In smoking the unlighted cigarette, the subject from time to time proceeded, on his own volition, to knock the imaginary ashes from the end of the cigarette. The amount of tobacco consumed in each smoking period was slightly more than two cigarettes.

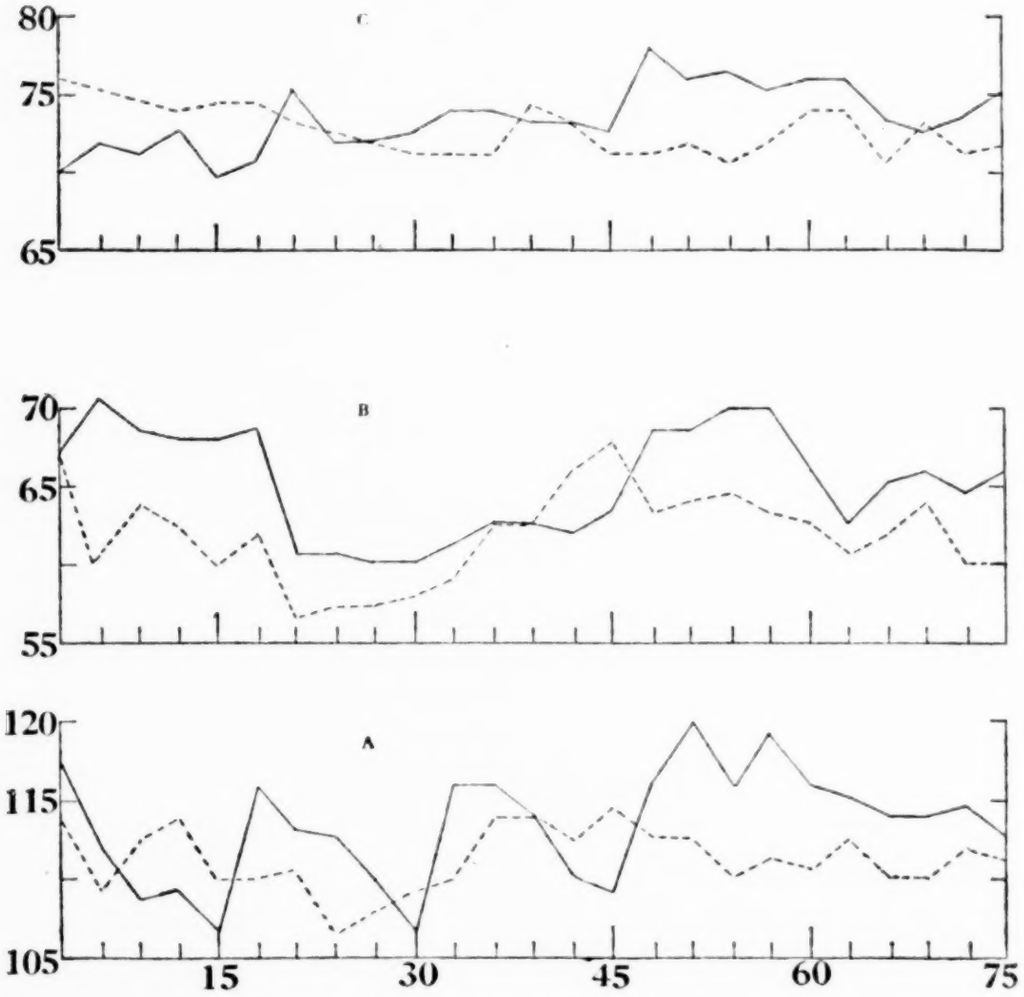

FIG. 1. Reactor 1. Averages for three days of: *A*, systolic pressure, and *B*, diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette, in the third period, followed by a lighted cigarette, in the fourth period. The broken line represents a lighted cigarette, in the third period, followed by an unlighted cigarette, in the fourth period.

To prevent any trace of the tobacco from reaching the reactor in the non-smoking periods, holders were used that were identical in design, except that the holder for the unlighted cigarette was so arranged that the usual passage way for the air was blocked with sealing wax, and behind

this barrier very small holes were bored through the holder which allowed the air to be easily inhaled without passing through the cigarette.

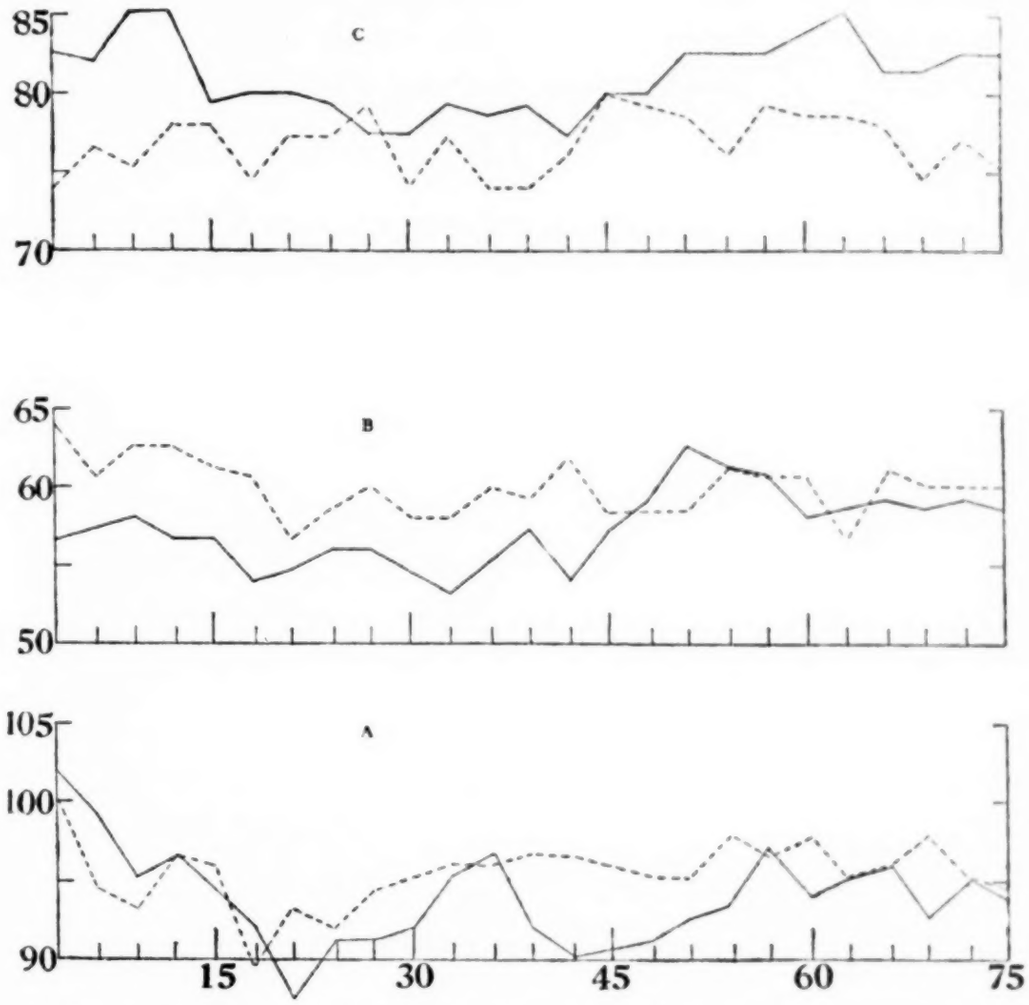

FIG. 2. Reactor 2. Averages for three days of: *A*, systolic pressure, and *B*, diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette, in the third period, followed by a lighted cigarette, in the fourth period. The broken line represents a lighted cigarette, in the third period, followed by an unlighted cigarette, in the fourth period.

The whole technique in this experiment was directed towards overcoming prejudices or counter effects of reason which occur when one endeavors to convince a subject by suggestion in the normal waking state. Upon the completion of the experiment an effort was made to determine whether the subjects had detected any differences between the smoking periods. Their replies indicated that they had detected no

differences and that they had no suspicion that in certain of the periods the cigarettes were unlighted.

Figures 1, 2, and 3 give a fairly clear representation of the effects produced by suggestion and of the effects produced by tobacco. Each curve represents the averages compiled for three days readings and each set of curves represents a

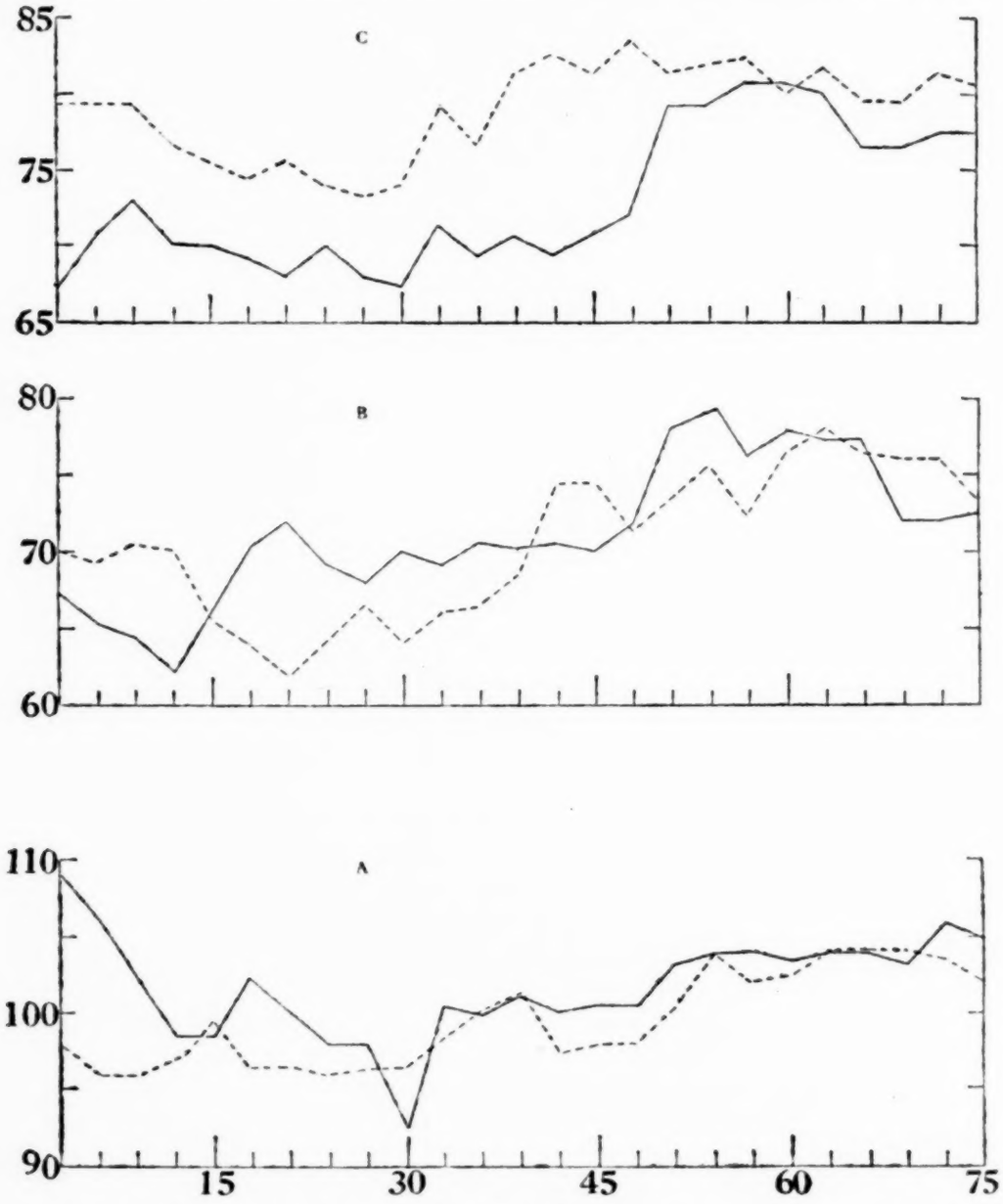

FIG. 3. Reactor 3. Averages for three days of: *A*, systolic pressure, and *B*, diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette, in the third period, followed by a lighted cigarette, in the fourth period. The broken line represents a lighted cigarette, in the third period, followed by an unlighted cigarette, in the fourth period.

different subject. The divisions of the curves are those mentioned in the procedure, *i.e.:*

1st, 15 minutes, Normal readings
2d, 15 minutes, Beginning of hypnosis
3d, 15 minutes, Lighted or unlighted cigarette
4th, 15 minutes, Unlighted or lighted cigarette
5th, 15 minutes, Discontinuation of smoking

All of these graphs show practically the same features for pulse rate, systolic pressure, and diastolic pressure. There is,

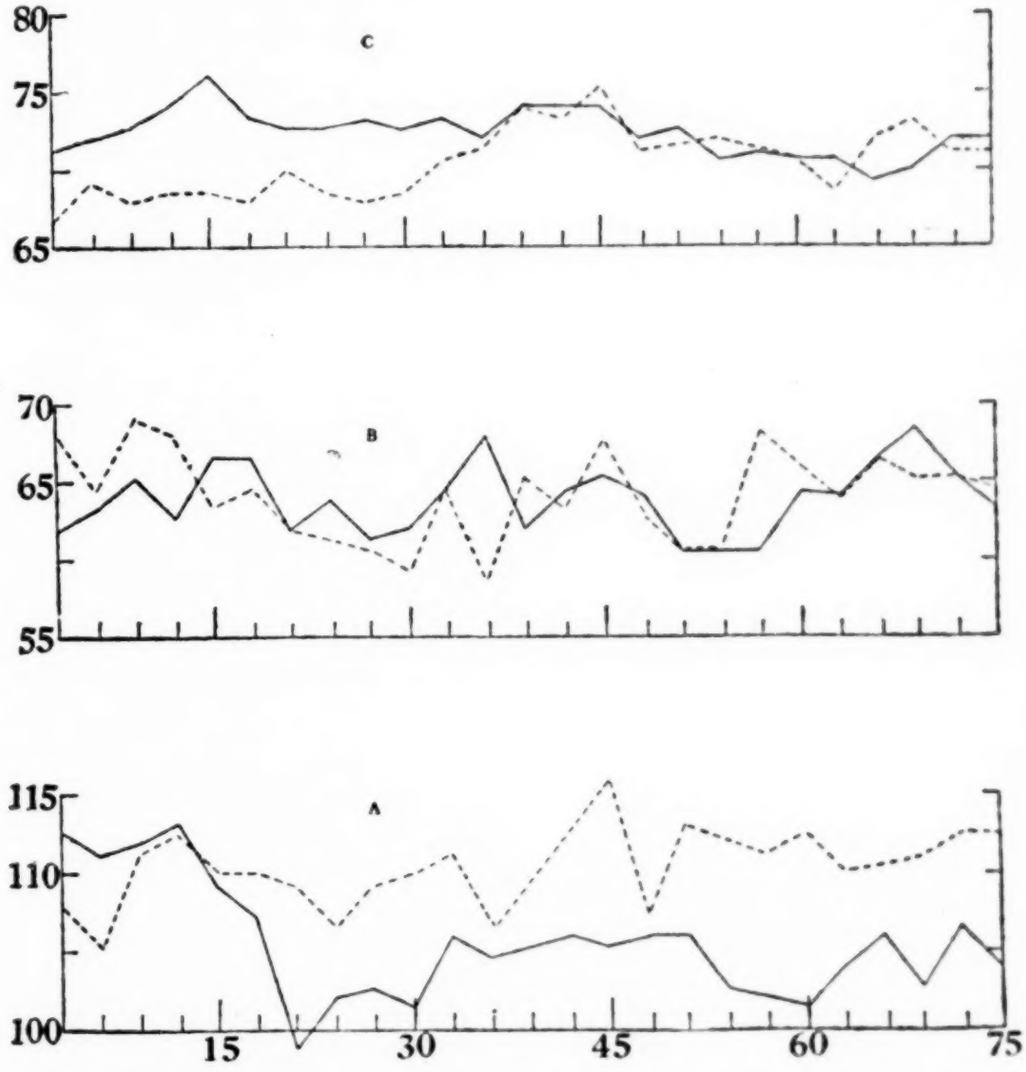

FIG. 4. Reactor 1. Averages for three days of: *A*, systolic pressure, and *B*, diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette in the third period. The broken line represents a lighted cigarette in the third period.

during hypnosis, a drop in blood pressure and pulse rate which is followed sometimes by a slight rise (usually of brief duration) in blood pressure following the introduction of an unlighted cigarette, which in turn is followed by a much greater rise in blood pressure and pulse rate when the lighted cigarette is introduced. There is a slight tendency towards a drop upon the completion of smoking, but the effects of tobacco seem to be great enough to keep the curves at a relatively high level until the readings are stopped.

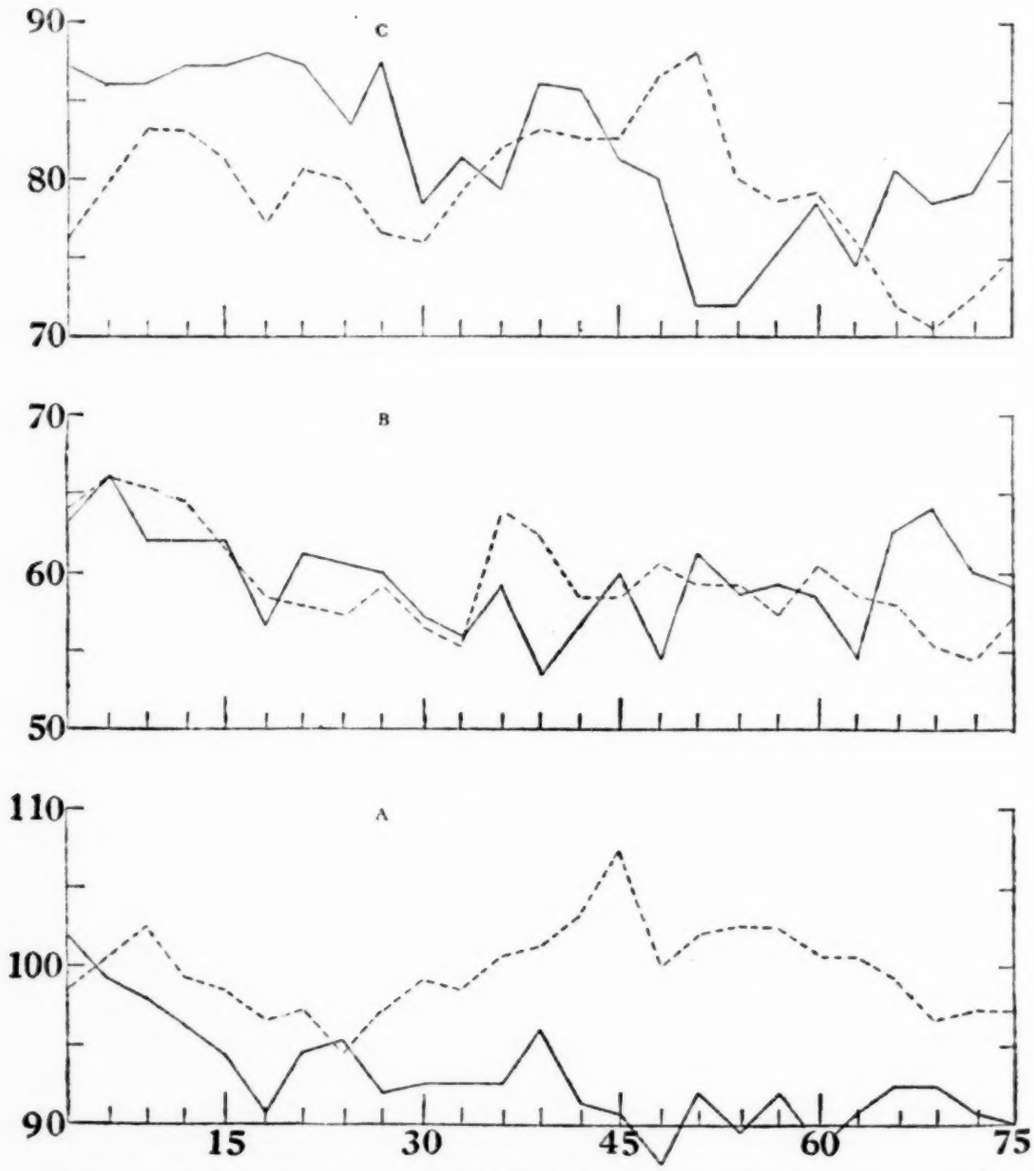

FIG. 5. Reactor 2. Averages for three days of: *A*, systolic pressure, and *B* diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette in the third period. The broken line represents a lighted cigarette in the third period.

Figures 4, 5, and 6, show the effects (for the same subjects) produced by smoking an unlighted cigarette or a lighted cigarette in the third period, followed by cessation of smoking

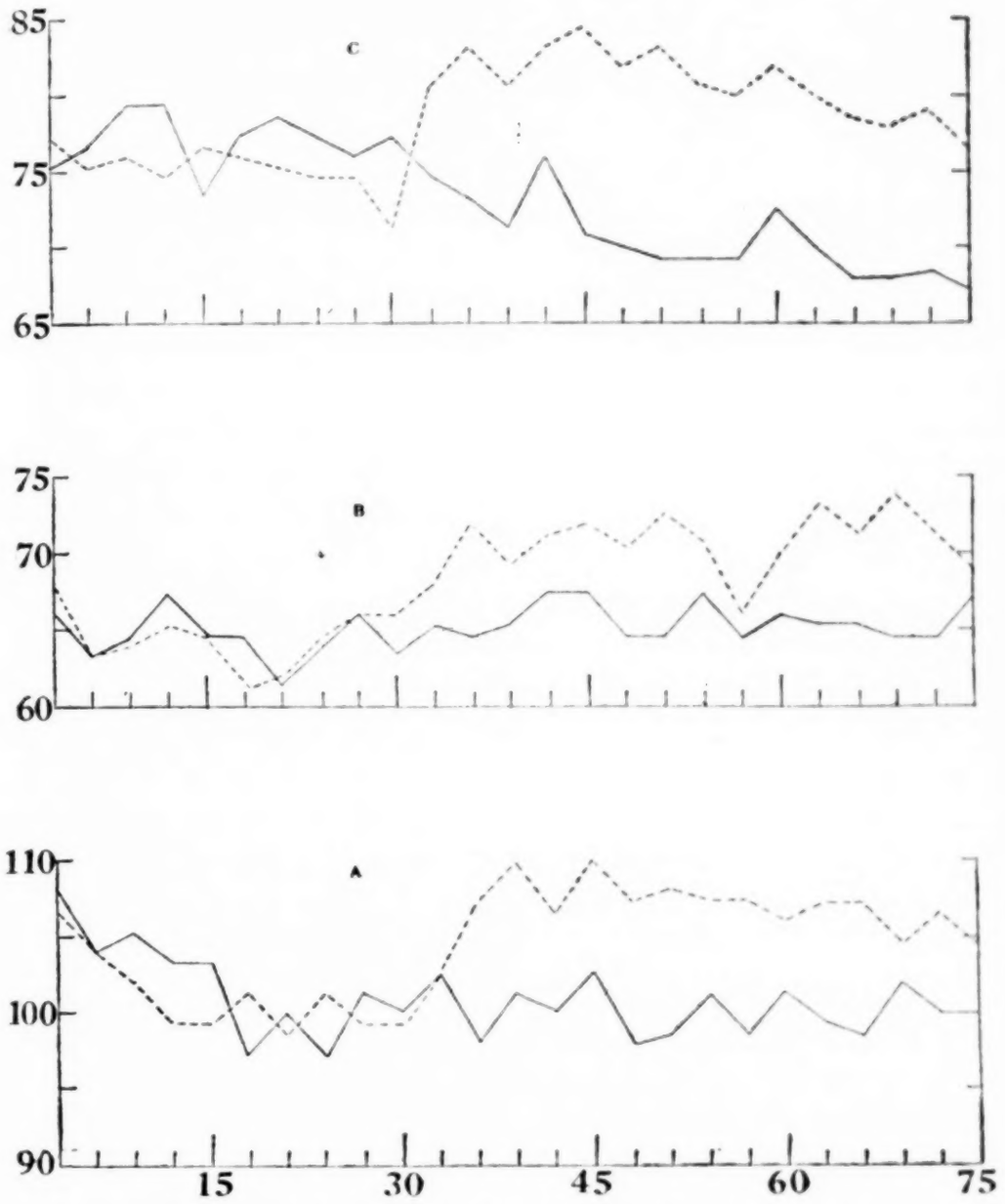

FIG. 6. Reactor 3. Averages for three days of: *A*, systolic pressure, and *B*, diastolic pressure, in millimeters of mercury; *C*, heart rate in beats per minute. The solid line represents an unlighted cigarette in the third period. The broken line represents a lighted cigarette in the third period.

for the next two periods. With the exception of the results shown in the curves for subject 1, the results are quite clear, and, even in that case, they are the same as the others,

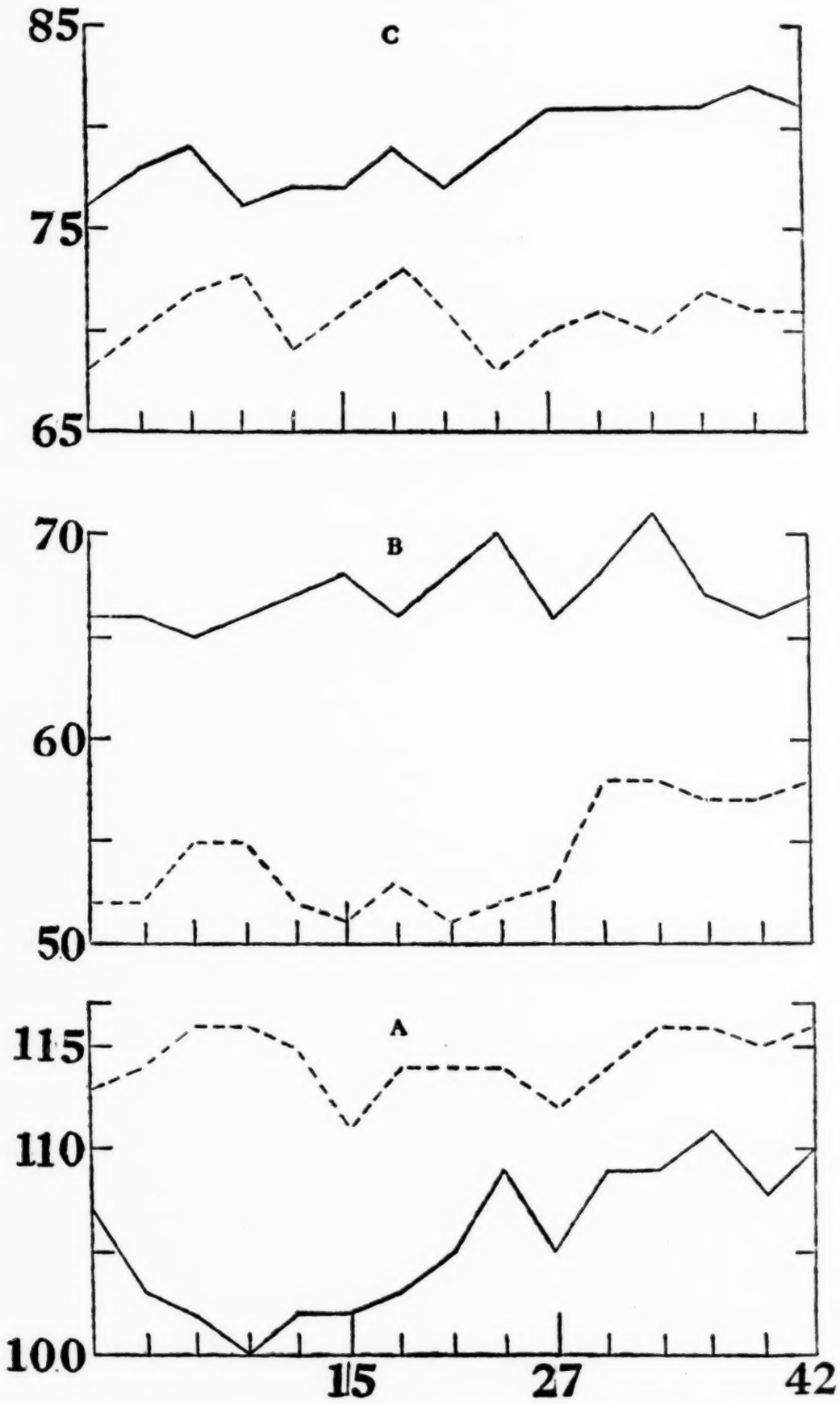

FIG. 7. Reactors 4 and 5. Averages for two days of: *A*, systolic pressure, and *B*, diastolic pressure in millimeters of mercury; *C*, heart rate in beats per minute. The solid line and the broken line represent reactors 4 and 5 respectively.

although there is not quite as marked a difference between the solid line and the broken line. There is a little more effect of suggestion for this subject than for the others. The rise in the broken graph for all the subjects takes place usually close to the beginning of the third period and continues through the fourth period. It is quite evident that the change produced is one that is caused by the effect of tobacco. The solid line for the three subjects, for pulse rate and systolic and diastolic pressure, shows very little rise, and the trend of the curve is downward. For subject 2, the pulse rate rises and is immediately followed by a rapid drop.

Figure 7 shows the results obtained from two other subjects under conditions dissimilar to those under which the other graphs were obtained. The subjects, under normal conditions (*i.e.*, without hypnosis), were asked to go through the act of smoking unlighted cigarettes and following this were asked to smoke lighted cigarettes (the amount of tobacco consumed being the same as in the previous trials).

The graphs for reactors 4 and 5 (Fig. 7) show about the same tendencies as do the solid line graphs in Figs. 4, 5, and 6. There is a rise in blood pressure and pulse rate when the reactors are conscious of the fact that they are only pretending to smoke, but the rise is not as great as in the case of the hypnotized subjects when they are smoking unlighted cigarettes. In both cases, however, the rise is inconsiderable, as compared with the effects of actual smoking.

An interesting fact was brought to light by this work which is not presented in the tables or in the graphs. There is a consistent increase in the intensity of the sounds produced by the heart beat when tobacco is smoked, a condition which is not present when there is only simulation.

Table I. shows the averages for the three subjects for the several conditions of the experiment. Hull does not report any changes for blood pressure, but for pulse rate he reports an average increase due to the effect of tobacco of three beats per minute. The results of this investigation show an increase of 4.9. His figure is, in all probability, more nearly that which would be found on the average, since two subjects

SHOWING THE AVERAGES IN THE CIRCULATORY FUNCTIONS FOR THE VARIATIONS IN PROCEDURE

	Systolic Avgs. Subject			Diastolic Avgs. Subject			Pulse Rate Subject		
	1	2	3	1	2	3	1	2	3
Normal	110.1	97.6	103	68.5	57	65	71	82.9	70.2
Hypnosis	111.7	90.8	98.2	62	55	70	72.5	78.8	68.5
Unlighted cigarette	113	92.9	100.3	62.4	55.4	70.1	73.4	78.9	70.2
Lighted cigarette	117.4	93.7	103	68.6	60.4	76.8	76.4	82.4	78.4
Cessation smoking	114.1	94.5	104.6	64.9	58.9	74.2	74.6	83.2	77.6
Normal	112	96.2	98	62.6	62.2	69	75.6	76.4	78
Hypnosis	108.6	92.9	96.5	58.2	58.8	64.2	72.8	76.5	74.2
Lighted cigarette	113	96.2	99.2	63.7	59.6	70	72.8	76.2	85.4
Unlighted cigarette	111.4	96.6	101.4	63.6	60.1	73.7	72	78.4	81.8
Cessation smoking	110.5	95.8	104.1	61.3	59.6	75.3	72.2	76.8	80.5
Normal	111.7	98	104.8	64	63	65.2	73.2	63	65.2
Hypnosis	102	93	99.2	63.3	59.2	63.8	72.6	59.2	63.8
Unlighted cigarette	105.4	92.6	100.9	64.9	57	66	73.4	57	66
Cessation smoking	103.6	89.8	99.6	62.1	58.5	64.8	71.4	58.5	64.8
Cessation smoking	104.6	91.3	100	65.3	60.1	65.4	70.9	60.1	65.4
Normal	109.4	100	102.2	66.6	64.2	65	68.2	81.4	75.3
Hypnosis	109	97.7	100	61.6	58	64	68.8	78.1	74.4
Lighted cigarette	111.2	102.2	107.3	64	60.2	70.5	72.9	82	82.5
Cessation smoking	110	101.6	107.2	64	59.4	70	71.2	82.4	81.6
Cessation smoking	110.8	98.2	106.2	65.5	56.8	71.8	71.3	73.3	79

in this experiment gave an increase of 3 and 3.5. If we consider the increase in pulse rate when only an unlighted cigarette is smoked we find the increase to be negligible. If, on the other hand, we consider the difference between the period in which the subject was only hypnotized and the period in which he was hypnotized and smoked, we find an increase of 5.4. Bates concludes that smoking has the effect of producing a rise in systolic and diastolic blood pressure, and in heart rate. The rises in blood pressure usually amount to but a few millimeters, above the previous average level, and are in almost all cases less than 10. The rise in heart rate is irregular; less than 10 per minute in most cases, but may be as much as 20. The figures which appear in Table I. tend to substantiate his statements rather thoroughly. The difference between actual smoking and 'supposedly' smoking

can be readily seen for the systolic and diastolic blood pressure readings as well as in the pulse rate.

It must be concluded that the increase in blood pressure and pulse rate which is produced by smoking is caused by physiological conditions rather than by psychical conditions, since the hypnotized subjects show little increase in any of the functions mentioned above, when they believe they are smoking and show a rather marked increase in those functions when they are smoking. There is also an increase in the intensity of the heart beat which is brought out by the smoking of tobacco.

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CRITICAL SENSITIVITY IN A PRESSURE REDUCER FOR THE PNEUMO-SPHYGMOGRAPH

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During the past fiscal year, there has been much popular interest stirred up in the city of Los Angeles over the use of the 'lie detector' in crime detection. While the records made by the machine were not introduced as court evidence for conviction or for clearing a suspect, still the apparatus did exert very great pressure in forcing many confessions. There were several criminals who stubbornly refused to admit anything under the ordinary third degree examinations, but when subjected to cross-questioning under the influence of the lie detector these same hard-boiled criminals broke down and admitted their guilt. As great as was the function of this 'humane' third degree machine in leading to the conviction of criminals it was just as valuable in freeing innocent persons from unjust accusations. Any means which can exert such a potential force as this deserves consideration so that its use may be more extensive. Obviously a beginning only has been made but time will certainly add improvements so that we may hope for an instrument which will be recognized in all criminal detection.

Just how reliable the cardio-pneumo-psychogram may be for proving that a witness does consciously deceive is a point upon which much valuable data is being collected. Mr. John A. Larson has made an extensive study of this. An article by Larson in the December 1923 number of this JOURNAL contains an account of his work in the Berkeley School of Police (which is under the direction of Mr. August Vollmer). This article contains a historical summary of previous contributions in this field.

The apparatus which Larson used was rather large though effective. It could not easily be carried from one place to

another. The chief reason for this was that he employed a long belt of smoked paper upon which the records were made. Everyone who has used smoked paper realizes the disagreeable work in its preparation for use and the shellacking process to make the record permanent.

An apparatus which eliminates the smoked paper and substitutes for it a nice clean strip of paper of any length, is certainly an improvement. Mr. Adelbert Ford has described such an improvement in the April, 1924, number of this JOURNAL. His apparatus, the 'Electro-Kymograph,' makes use of a high voltage, high frequency electric current which punches a series of tiny holes, close together, through the paper. Each little hole is made directly under the tip of the recording needle. The manifest advantage of this device is that one may make a record of any length and eliminate the friction between the point of the needle and the paper. This is a very great improvement.

It is possible to make an inked record on paper if the friction between the pen point and the paper is reduced and if a greater driving force on the pens may be obtained. Below there is a description of an apparatus by which excellent records were made using ink on paper. A special inking point was constructed which gave very little friction and which was easy to adjust. It was designed to have very little inertia and yet have an abundant supply of ink. Larger driving forces were obtained by a specially constructed pressure reducer so that records of variation of blood pressure were made in which the amplitude was as great as one inch or more. An instrument was constructed in accordance with the following description, which was used in making hundreds of police court records. This machine weighed about twenty pounds, so that it was easy to carry. Another machine was made for use by students who were doing some investigations in the psychological laboratory.

The apparatus consists of the rubber sleeve, a pressure reducing device, Marey's tambour, a light glass lever and stylus, a roll of smooth paper and a kymograph or a motor driven drum for winding up the paper. The line diagram (see

Fig. 1) shows the arrangement of the essential parts. The new feature is the pressure reducing device. The instrument is so designed that it is peculiarly sensitive to small changes of pressure. This characteristic makes it therefore especially

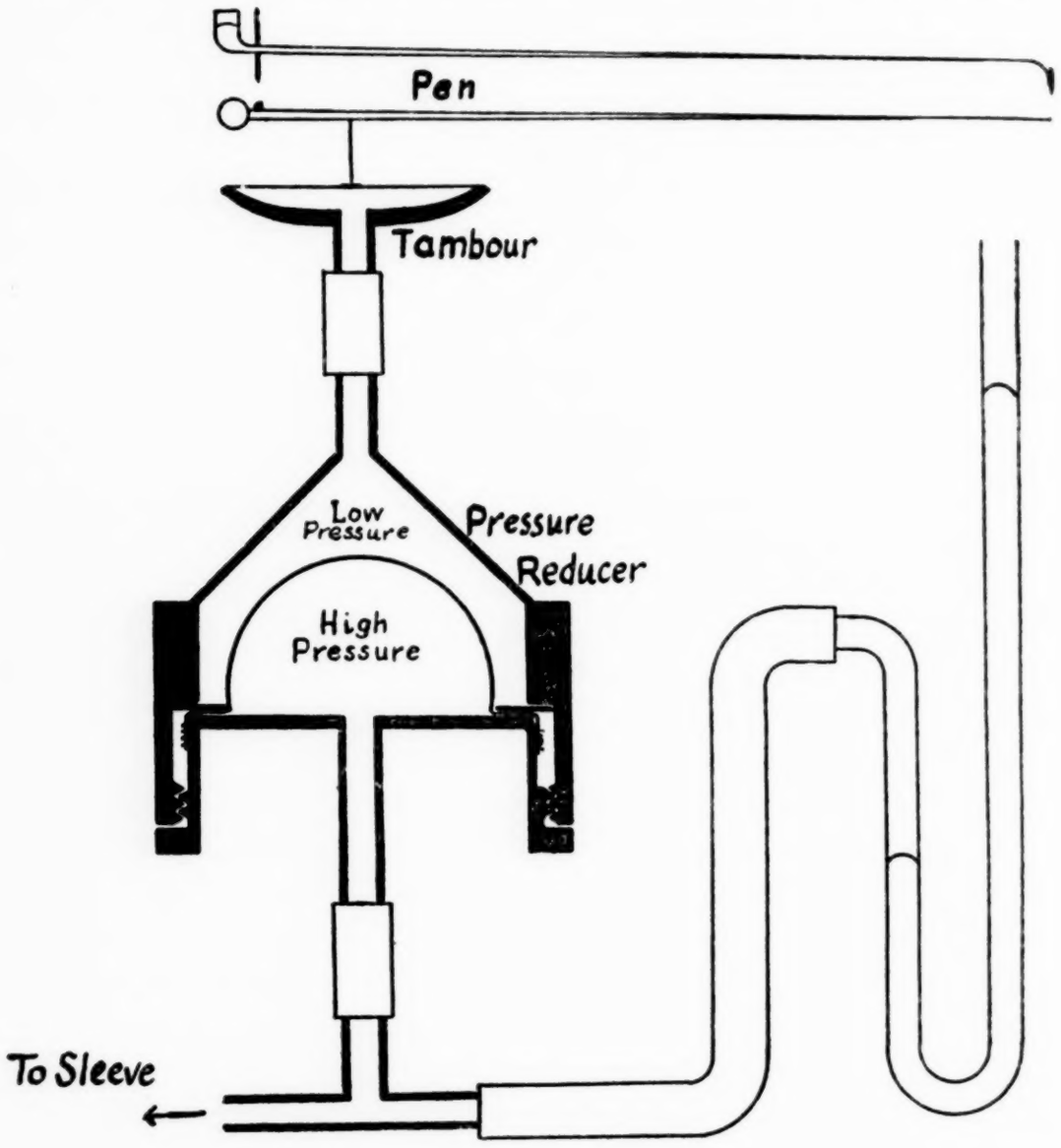


FIG. 1

adapted to the sphygmograph. A circular piece of sheet rubber is fastened in the pressure reducer so that it separates the two masses of air which are at different pressures, and transmits the impulses due to variation of blood pressure from the high pressure chamber to the low pressure chamber leading to the tambour. When air is pumped into the high

pressure chamber of the pressure reducer the volume of the confined air increases as the pressure increases, up to a certain amount at which the pressure decreases even though more air is introduced. An inspection of the graphical relation between pressure and volume in the accompanying cut (Fig. 2)

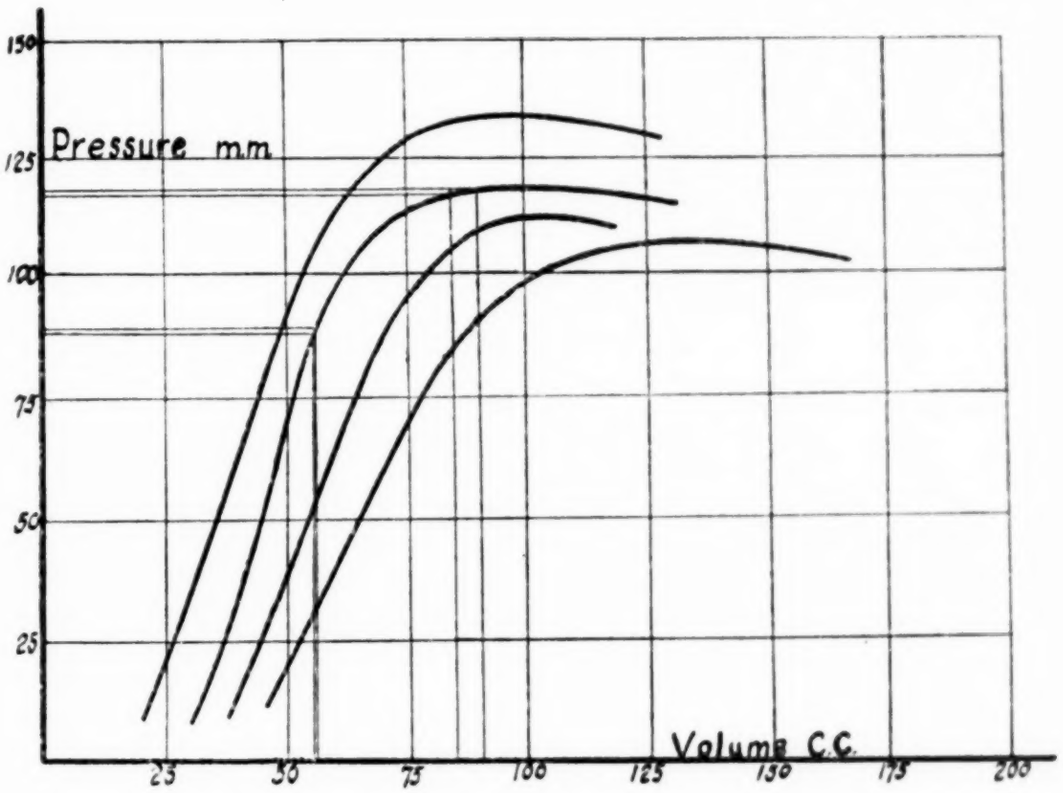


FIG. 2

shows this characteristic. The volume increases as the pressure increases up to a critical pressure, beyond this point the pressure diminishes. This is noticeable on each of the four curves given. Each curve has its own critical pressure which differs from the others only in the magnitude of the pressure. It is obvious that a small change of pressure on the nearly straight portion of the curve produces a correspondingly small change of volume. But if the small change of pressure occurs near the crest of the curve a very much larger change in volume is produced. Such a characteristic feature is especially useful in the sphygmograph, for, when this is critically adjusted, the pressure reducer causes a larger and stronger movement of the diaphragm in the tambour.

The crest of the pressure volume curve may be made to occur at any desirable pressure by properly limiting the expanding portion of the rubber. In the instrument used for this study, the sheet rubber was one thirty-secondth of an inch thick. Thin metal discs having holes varying in diameter from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches were made to fit into the pressure reducer as shown in the cut. Critical pressures were thereby obtained which varied from 95 mm. to 150 mm. of mercury. This range might be extended if desired.

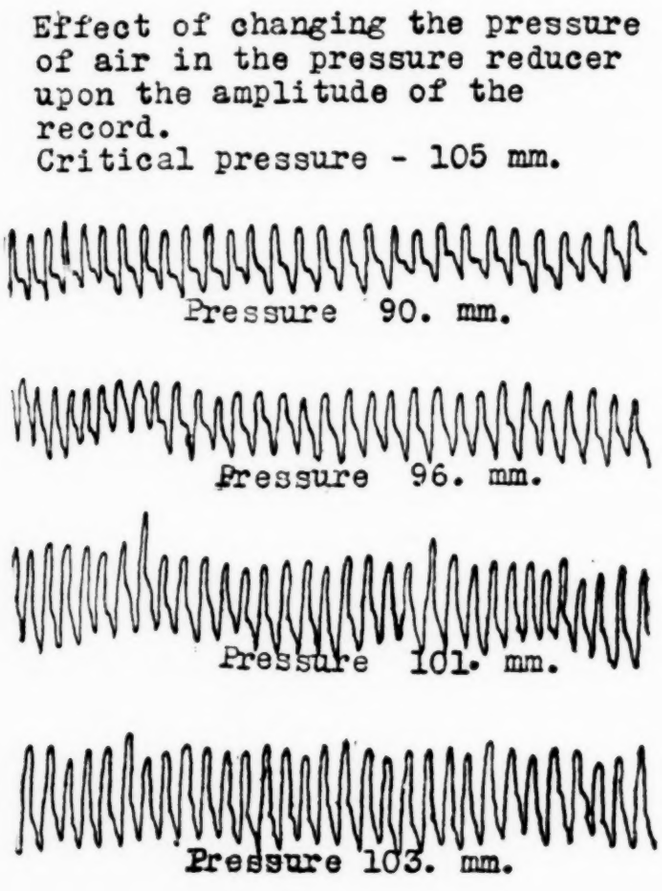

Effect of changing the pressure of air in the pressure reducer upon the amplitude of the record.
Critical pressure - 105 mm.
Pressure 90. mm.
Pressure 96. mm.
Pressure 101. mm.
Pressure 103. mm.

FIG. 3.

In obtaining a blood pressure time curve, the air pressure in the sleeve should be but two or three mm. below the critical pressure of the disc used. The blood pressure of the individual may be first determined and then the proper disc inserted in the pressure reducer. It was found more practical to use a disc which had a critical pressure some 15 or 30 mm. below the blood pressure of the subject, thereby causing less

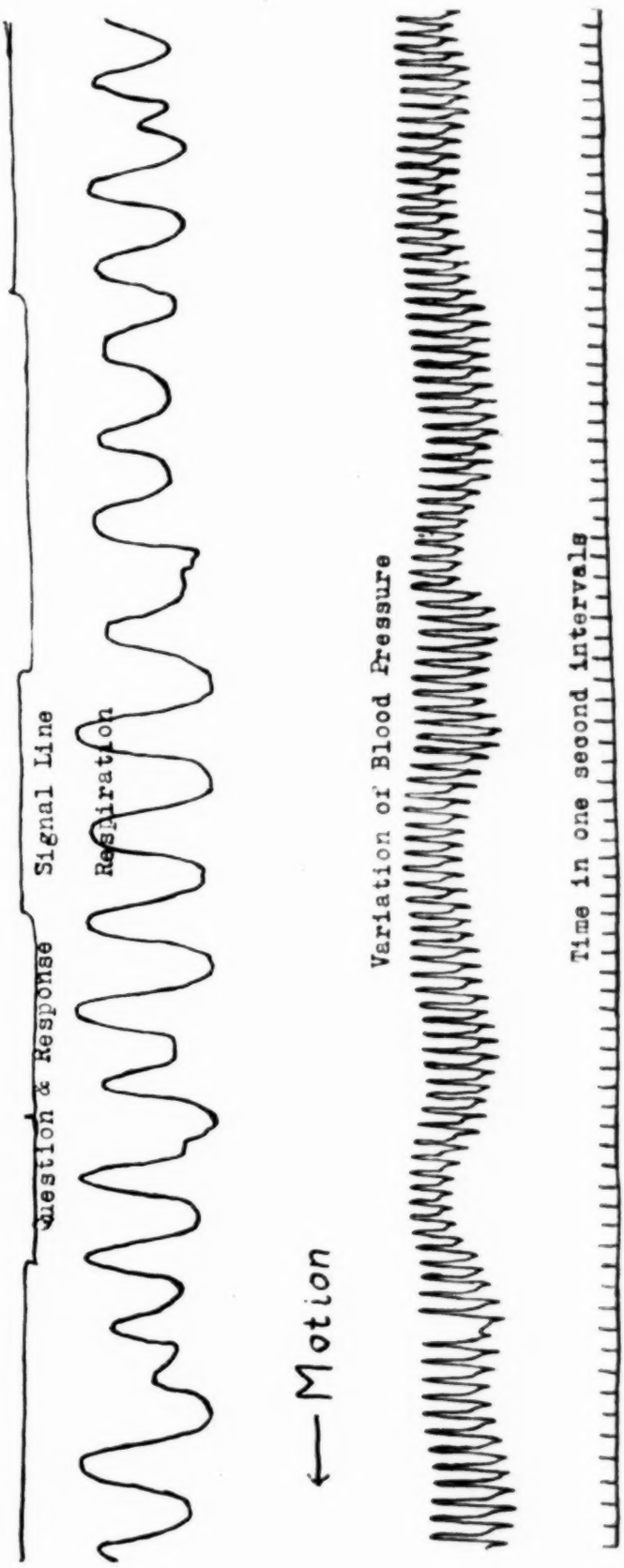


FIG. 4. Normal reaction

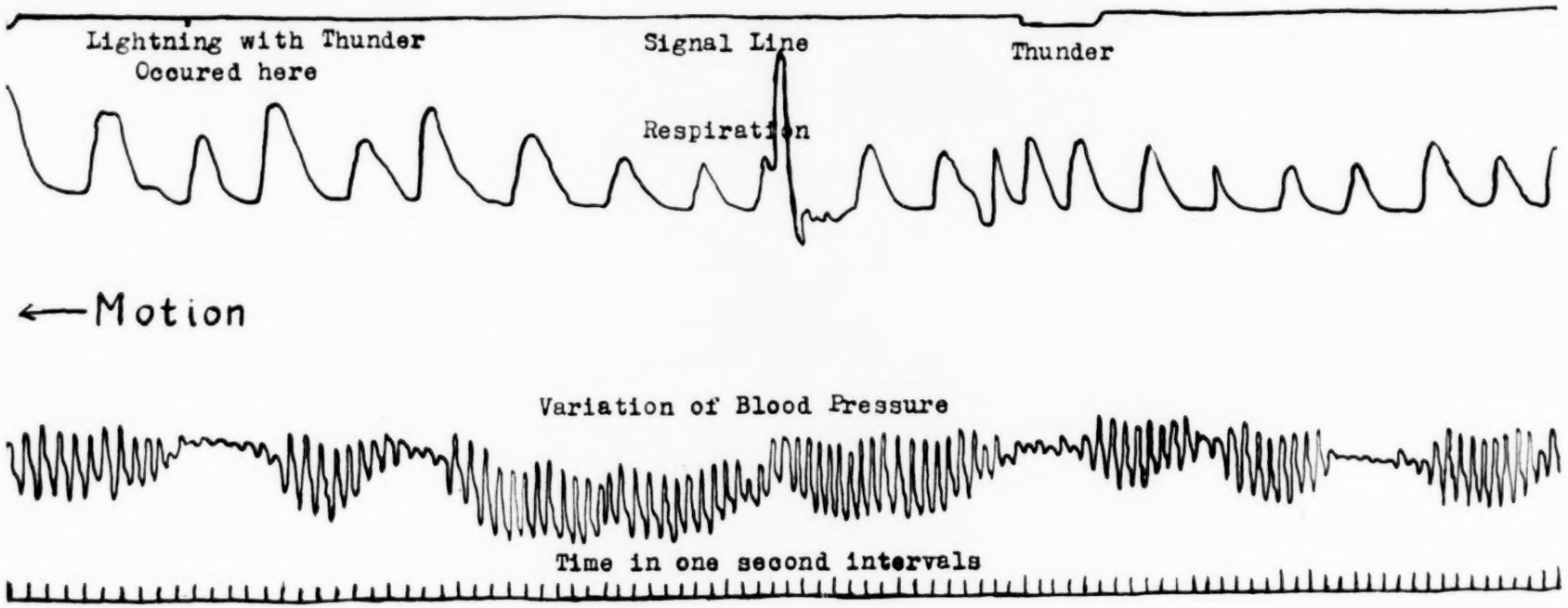
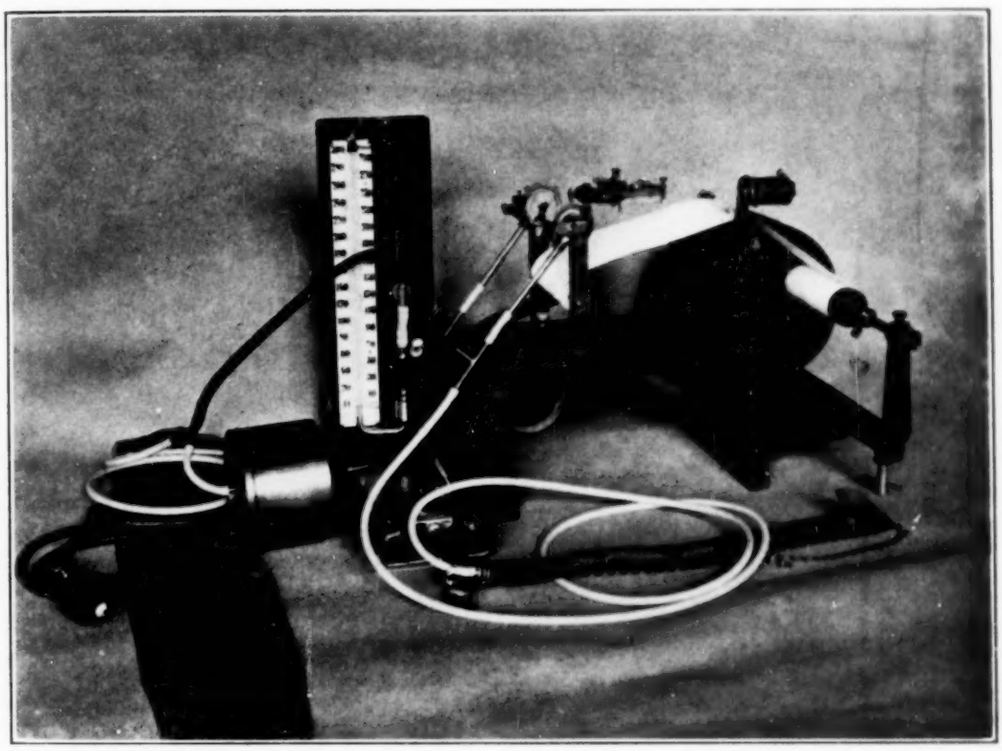


FIG. 5. Reaction showing fear

discomfort and permitting longer records without any sacrifice of amplitude. Larger changes of pressure were obtained by putting the sleeve just below the knee on the upper calf of the leg, but in some cases the sleeve was used on the upper arm with equally satisfactory records.

The accompanying records of blood pressure were made on an individual whose blood pressure was 122 mm. The pressure reducer was arranged to have a critical pressure of 105 mm. The amplitude of the record increases noticeably as the pressure in the sleeve approaches the critical pressure.



The glass lever pen was drawn from $\frac{1}{4}$-inch glass tubing so that the smaller end was about 0.25 mm. in diameter. It was fastened to a steel pivot near the larger end. Motion was in a horizontal plane. To the smaller end was fastened a fine pointed piece of bamboo which served as the inking point. Adjusting screws served to control the pressure of the pen point upon the paper. Any good fountain pen ink was found to be satisfactory. Very thin rubber was used on the tambour and this was allowed to be somewhat loose, not tightly

stretched. The moment of inertia of the whole inking system was as small as could be easily made so that a more exact record of the pressure variation could be made than is possible with the heavier steel levers.

One very commendable feature of the apparatus was the fact that the time record was not limited to a few minutes. Records were made continuously for 20 minutes or more if desired. With the apparatus constructed for experimental work in this laboratory, it was found convenient to make simultaneous records of the blood pressure, respiration, time and signal, upon the one strip of four-inch paper. Two samples of the four simultaneous records are shown. In one a normal reaction showing emotion under questioning is noticeable. In the other the effect of fear is clearly shown. In this case the fear was caused by a convenient thunder storm.

THE DISTRIBUTION OF TONE IN SKELETAL MUSCLE

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The phenomenon of muscle tone is a well-known physiological fact. The investigations of Lombard (1), Dodge (2), Tuttle (3), and others have shown that the knee-jerk is an index to the change of tone, at least in the muscles involved in this reflex. The fact that muscle tone is ever changing is shown by the irregularity in the knee-jerk, whether the extent of the kick or the change in the thickness of the muscles involved is considered as the tonic index. The purpose of this investigation is to determine whether or not there is a direct correlation between the change of tone in different members of the body. While studying a number of factors influencing the knee-jerk, a group of data collected from one subject presents evidence upon the point in question.

The subject used in this experiment is a student in the University and is normal in every respect as far as the writer is able to determine. By observing his general behavior, however, one would place him in the hyperirritable group. This conclusion is further justified by observing his knee-jerk. It is much higher than the average and the slightest change in the environment causes an unusual irregularity in the extent of the jerk.

While the subject in question was delivering knee-jerks for another experiment he was observed responding with both legs, even though only the ligamentum patellæ of the right was being stimulated. Since the writer had in mind comparing the change of tone as exhibited by the knee-jerk in both legs, this situation offered an opportunity for collecting the data herein reported.

The data were collected by means of an especially constructed apparatus described in detail elsewhere (4). The

method was so modified that simultaneous records of the jerks of both legs could be recorded. The stimuli were delivered to the center of the ligamentum patellæ at the rate of seven per minute. The force of the stimulus was 50 grams. Although only one subject was available, this type being rare in the experience of the writer, a total of 144 pairs of kicks were obtained and are used as a basis for the conclusions herein drawn. No special tasks were assigned to the subject. After he was adjusted in the apparatus he engaged in conversation with the operator and carried on as he saw fit, taking care not to alter the place of impingement of the stimuli.

Figure 1 shows simultaneous responses of the right and left legs, the ligamentum patellæ of the right only being stimulated. The upper tracing is that of the right leg and the lower that of the left.

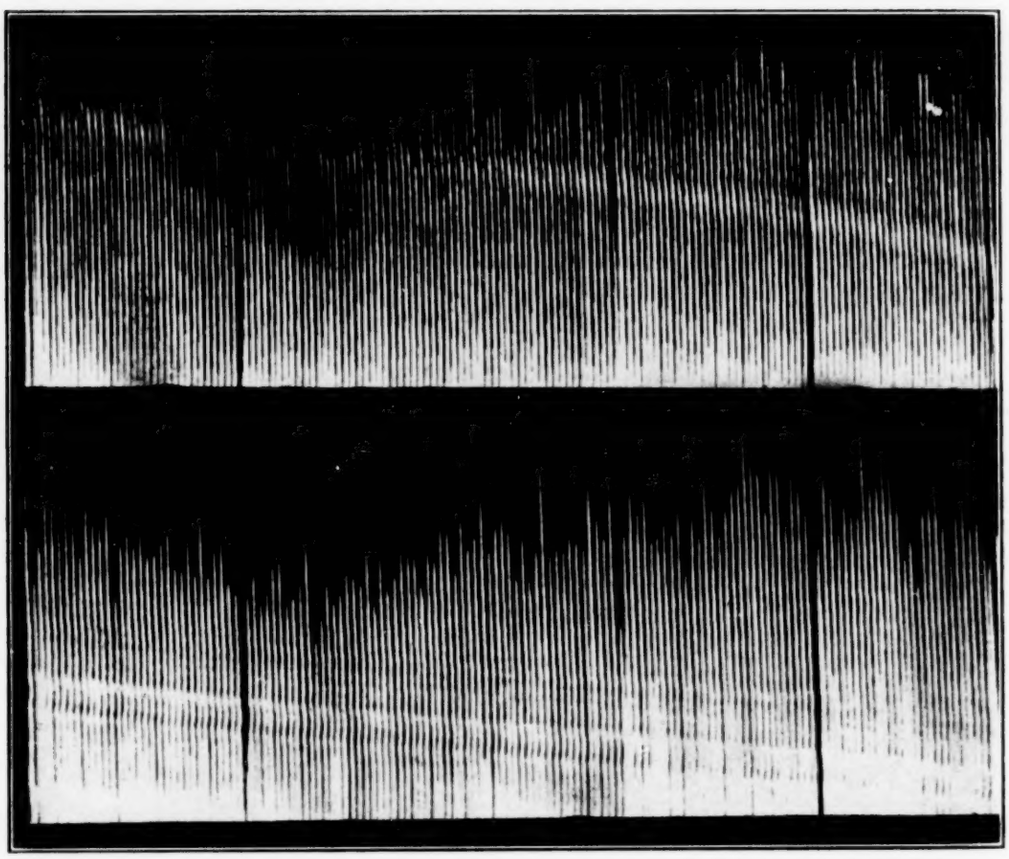

FIG. 1. This record shows simultaneous tracings of the knee-jerk of both the right and left leg. Although both legs respond, the stimuli were applied only to the ligamentum patellæ of the right.

By mere observation it is easily seen that in general the heights of the kicks of both legs are very similar. Where there is an outstanding high or low response in one record, there is a corresponding high or low response in the other.

Table 1 shows a comparison of the height of the 174 pairs of kicks.

Difference in Height in Mm.	No. of Pairs	Per Cent.
0	34	23.64
1	32	22.21
2	24	16.67
3	27	18.75
4	18	12.50
5	5	3.48
6	3	2.08
8	1	0.69

Considering the group as a whole the average height of the kick for the right leg is 52.54 millimeters and for the left, 51.86 millimeters, a difference of .68 millimeters. This difference is so small that it may be neglected. Although a comparison of the average height of the kick shows nothing with respect to similarity, it does show that in general the total heights kicked are the same in this experiment.

A further comparison of the data was made by computing the coefficient of correlation (5) between the two groups of data which was found to be .970.

Only about 6 per cent. of the pairs of kicks showed a difference of 5 mm. or over. Differences of less than 5 mm. can be counted experimental errors due to friction, inertia, etc. At the time of this experiment it was impracticable to determine whether it is possible to change this close correlation by imposing various tasks or administering various drugs during the time the record was being made.

Summary

As shown by the knee-jerks of both legs of the subject used in this experiment, whatever increased or decreased the tone in one thigh increased or decreased it to the same extent in the other, when the subject responded only to periodic stimulation

of seven blows per minute administered to the ligamentum patellæ of the right knee only.

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AN ALTERNATIVE FORMULA FOR THE TRUE CORRELATION OF INITIAL VALUES WITH GAINS

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In the JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 1924, VII., 321, there was obtained a formula to give correct correlations between gains and initial values, which in a raw state are vitiated by errors of measurement producing a complication of the attenuation effect. The object of this short note is to give an *alternative* to equation 11 in that paper, viz.:

$$r_{ag} = \frac{\sigma_z r_{xz} - \sigma_x r_x}{\sqrt{r_x(r_x\sigma_x^2 + r_z\sigma_z^2 - 2\sigma_x\sigma_z r_{xz})}}, \qquad (14)$$

which is algebraically identical and is in some situations more convenient as it only needs information about x and z and does not require that the measured gains $y = z - x$ be even ascertained. I have numbered the equation 14 in continuation of the previous paper, and here, as there, the symbols have the following meanings:

a = a true initial value,
g = a true gain,
r_{ag} = their true correlation,
x = the measured initial value,
r_x = its reliability coefficient,
z = the measured final value,
r_z = its reliability coefficient,
r_{xz} = their crude correlation,
σ_x and σ_z = their respective sigmas,
$y = z - x$ = measured gain.

r_{ag} is therefore the true value of r_{xy}, the calculation of the latter being however unnecessary in the present formula.

The new formula 14 can easily be obtained from the old by using the facts that

$$2\sigma_x\sigma_z r_{xz} = \sigma_z^2 + \sigma_x^2 - \sigma_y^2$$

and

$$2\sigma_x\sigma_y r_{xy} = \sigma_z^2 - \sigma_x^2 - \sigma_y^2.$$

Both formulæ assume that the errors are uncorrelated. I may take this opportunity of correcting a misprint in the last line of page 322 in the former article, where $\sigma_{e_1}^2$ should read $\sigma_{e'}^2$.